UNEP Greenhouse Gas Abatement Costing Studies

India Country Study
Phase Two
(Final Report)

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9 Jor Bagh,
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Project Team

Dr. P Ghosh	Senior Fellow
Ms. Anjana Das	Research Associate
Ms. Neha Khanna	Research Associate
Ms. Sharmila Barathan	Research Associate
Mr. Gautam Sethi	Research Associate
Ms. Meena Kumari	Private Secretary

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Glossary

ATF - Aviation turbine fuel
BOP - Balance of Payment
FO - Fuel oil
GDP - Gross Domestic Product
GHG - Green House Gas
HSD - High Speed Diesel
LPG - Liquified petroleum Gas
MS - Motor Spirit
PCFP - Pulverised Coal Fired Plant
PKMS - Passenger Kilometers
PLF - Plant Load Factor
SKO - Superior Kerosene
TKMS - Tonne Kilometers
TV - Television

Energy Units

GJ - Giga Joules (10^9 Joules)
PJ - Peta Joules (10^{15} Joules)
Twh - Tera watthours (10^{12} watt hours)

CHAPTER 1
PERSPECTIVE OF THE STUDY

1.1 Introduction

The India country study has been carried out by a team of researchers at the Tata Energy Research Institute, New Delhi (TERI). For the study, the existing "Tata Energy-Economy Simulation and Evaluation" (TEESE) model has been extensively revised, updated, and model code rewritten in the GAMS software. The TEESE model is a bottom-up engineering model which furnishes sets of technology choices in an economy premised on minimizing annual levelized economic cost of the energy system, and subject to specified technical and resource constraints. The new version incorporates a constraint on *aggregate* CO_2 emissions.

The Phase Two Collaborative Study is subtitled: "Analysis of Abatement Costing Studies and Preparation of a Methodology to Undertake National Greenhouse Gas Abatement Costing Studies". The subtitle would suggest that the principal objective of the collaborative study is to develop a methodology for abatement costing studies, rather than to compare estimates of abatement costs across countries. The guidelines for carrying out the studies are contained in the Working Paper of 25 September 1992 (called "guidelines" hereafter).

The content and structure of the studies is furnished in Section 3 of the guidelines, and illustrated in Figure 3.1. It comprises four different "analysis processes": Data, Analysis, Models, and Social Political and Economic assessment. The experience of the India country study with respect to each of these aspects is detailed below:

1.2 Data

Data for the study has been specified in the guidelines in three categories: *macroeconomic forecast*, containing general economic forecast, assumptions concerning fuel prices, discount rates, etc; *technology and emissions* data containing production technology and GHG emissions (for the energy sector it contains energy supply and demand technologies and emissions factors related to fuels and conversion technologies); and *technical options for GHG abatement* containing technical data and direct related costs for GHG abatement options.

In carrying out the study, in respect of "macroeconomic data", future projections of GDP and final demands of goods and services in the economy in different sectors has been made for each of the terminal years, 2009/10 and 2019/20. Actual data is available for 1989/90. Such projections have also been made for aggregate population and its distribution across rural and urban areas, and in different income classes. Assumptions of future international fuel prices have been furnished in the guidelines, and these have been employed in the study. A social discount rate of 10 percent per year has been employed in the study, as suggested in the guidelines. Alternative analyses with a social discount rate of 3 percent per year, also suggested in the guidelines, could not carried out because data to compute domestic costs of production of different fuels with this discount rate was not available.

A large data base (> 100 technologies) was also prepared in the course of the study, for technology and emissions data in production as well as energy sectors. This data had to be collected from agencies with actual experience of operating the respective technologies in India, in particular for costs, i.e., capital investment as well as operation and maintenance. A major international technology data base to which the team had access proved to be of no value, because the data was not sufficiently disaggregated or detailed to permit computation of costs of technologies in India. Accordingly while the team claims that the technology data set employed in the analysis is sound, it does not include either exotic or futuristic technology options for which there is no operating experience in India.

Technologies are not distinguished in the database as "conventional" and "abatement". The reason is simple. Many current practices in India are GHG benign, and have no counterparts which would qualify to be abatement options. For example, much of the household sector relies on biomass energy. This energy source is considered to be neutral in terms of carbon emissions, unless there is evidence that its use results in loss of carbon sinks or land use changes involving release of soil carbon, for example due to deforestation. Since the actual evidence is to the contrary, i.e., there is net annual *reforestation* in India, the assumption of carbon neutrality of biomass energy in the study is justified. The alternative to biomass energy use in households, i.e., commercial energy carriers (fossil fuels, electricity), are typically net carbon emitters.[1]

Several policy options for GHG abatement in India would therefore involve *restraints* on shift from, or possibly *reversion* to, traditional practices. The data category of "technical options for GHG abatement" is thus part of the data set on "technology and emissions data". The bottom-up model employed in the study chooses the sub of technologies for each scenario from this technology data set, given the set of constraints imposed, and the objective function.

1.3 Analysis

There are four steps in the analysis process. These are, *reference scenario*, i.e., the reference point for both cost and emissions for the abatement analysis as a whole; *ranking of GHG*

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[1] Except perhaps when electricity is supplied by solar or windpower, neglecting CO_2 emissions embodied in the plant and equipment.

abatement technologies, i.e., an estimate of the cost and GHG reduction potential for the abatement options "to obtain an initial impression of which technologies should be introduced first in the abatement process"; *GHG abatement scenarios* i.e., the integrated scenario analysis, where all linkages in the production system are taken into account; and *macroeconomic assessment* i.e., analysis of the effects of different production systems and GHG abatement policies on the national economy as a whole.

The construction of the "reference scenario" presented certain difficulties. The guidelines suggest that it should be a "business-as-usual" (BAU) scenario, i.e., "if the country does not comply with its obligations under the climate change convention....this means that the reference scenario must include any efficiency improvements in energy demand and supply technology which are *expected to occur* in any case". Two major problems that were encountered are as follows: First, the replication of the existing (1989/90) energy scenario requires detailed information on the inventory of technologies. This is because while the pattern of final demands of goods and services in 1989/90, as well as the pattern of energy supply and consumption are known, just this information allows multiple solutions to the question of energy system cost, because it is compatible with several different technology inventories.[2] A run of the model furnishes one such solution, i.e., that corresponding to least-cost. However, there is no reason to suppose that the actual technology inventory (and hence energy system cost) in 1989/90 corresponds to this solution. Since the starting point is uncertain, its projection into the future to generate a BAU scenario is not possible. Second, it is not possible to categorically identify a set of expected efficiency improvements. This is because any efficiency improvements would depend on the rates of penetration of efficient technologies. While the technology data set does include more efficient versions of several technologies, an answer to the question of their respective rates of uptake under a BAU projection would be pure guesswork since little empirical data is available. Assumptions regarding such expected efficiency improvements would thus be hardly defensible. Any BAU projection on this basis would have little credibility as a prediction.

Since the study does require a reference scenario, the following procedure, which yields a scenario with an *unambiguous interpretation*, was adopted: Runs of the model were made for each terminal year (1989/90, 2009/10, and 2019/20) with all technical and resource constraints intact, but with no CO_2 emissions constraint. The solutions (technology inventories, CO_2 emissions, energy system costs) comprise the reference scenario. The interpretation of this reference scenario is that it furnishes the *lower bound of energy system*

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[2] The energy system cost is the sum of levelized annual costs of the different technologies comprising the inventory.

costs at each terminal year, given that macroeconomic projections are valid, and given the specific technical and resource constraints included in the model, and under the further assumption of no policy commitment to CO_2 abatement. The subset of technologies employed in this solution, taken together, constitute the "no-regrets" options as conventionally defined.

The task of *ranking of GHG abatement technologies* also proved impracticable. We have noted above that there are no abatement options for several current practices in India. A further difficulty is that even where abatement options may be tentatively specified, the actual abatement achieved by means of each option depends on the *assumed* overall structure of the energy system. To illustrate: If compact fluorescent lamps are taken to be an abatement option in relation to conventional incandescent lamps, the question of extent of abatement depends on what is the (marginal) source of electricity. If the electricity comes from hydropower, for example, there would be no CO_2 abatement. Any ranking of abatement options would thus be specific to the set of assumptions made about the structure of the entire energy system, and thus would hardly give a valid "initial impression of which technologies should be introduced first in the abatement process". It is important to remember that since the entire energy system is interlinked, the introduction of an abatement option may itself alter the structure of the energy system. Owing to these conceptual and practical difficulties, this part of the analysis was not performed.

The *GHG abatement scenarios* were analyzed by means of runs of the (reformulated) TEESE model for each terminal year, for the specified percentage reduction of CO_2 from the baseline, i.e., the reference scenario. The costs of reduction are in each case the difference between the energy system costs in the abatement scenario and the reference scenario for the same terminal year. Because of the way in which the reference scenario is defined, all abatement costs are positive.[3] In each abatement scenario, the energy system cost has an *unambiguous interpretation*, i.e., it is the least cost for meeting both the projected final demand vector of goods and services in the economy, and the aggregate CO_2 constraint for that scenario.[4]

The *macroeconomic assessment* furnished by the study is the *absolute* energy system cost in each abatement scenario, or alternatively the *incremental* energy system cost in relation to the reference scenario. A comprehensive macroeconomic assessment may be made for a given specification of the resource endowments of the economy, the feasible technology choices, the policy instruments employed, the aggregate CO_2 constraint, and the relevant aspects of the external economic environment. The assessment may include estimates of GDP, welfare levels in terms of a defined index, relative factor rewards, the structure of production, private and public consumption, the composition of international trade, and possibly other aspects depending upon interest. Such an analysis would require a validated macroeconomic *predictive* model of the economy, which the project team did not have access to. Purely intuitive macroeconomic assessments are notoriously misleading because of the dense second and higher order linkages that exist in an economy, about which intuitive grasp is extremely difficult. In any case, the starting point is a *sufficient specification of the structure of the economy in each abatement scenario*, about which detailed comment follows:

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[3] The difference between each abatement scenario and the reference scenario for that year is the CO_2 constraint. Because an additional constraint is imposed, the value of the objective function minimized by the linear program, i.e., energy system cost, increases.

[4] The CO_2 constraint in the model is expressed in quantity terms. The quantity in each case is derived from the specified percentage reduction from the reference scenario.

The guidelines specify that "The output of this analysis could be (to) *provide the basis for a national GHG abatement strategy* which would comprise a comprehensive social, political, and economic plan for the implementation of GHG abatement. *The UNEP study does not seek to develop such a strategy for the countries concerned*; it merely focuses on providing relevant information". The *strategy* is thus a *plan* for implementation of GHG abatement. The abatement scenarios should thus furnish a specification (prediction) of the structure of the economy, enabling both a macroeconomic assessment[5], as well as formulation of an abatement strategy. To our minds, this is an impracticable exercise. The reasons are discussed below:

1.4 Models

The analysis is to be carried out by means of a formal quantitative model. Such models are of two basic types, i.e., *behavioral or predictive* and *prescriptive*.[6]

Predictive models in the social sciences always face a problem of empirical validation, since the real world cannot be exposed to exogenous shocks to test the model. Accordingly, their credibility depends upon the structure of the (principally) behavioral assumptions built into the model. Builders of such models are thus careful to ensure that these behavioral assumptions either have a strong basis in (economic) theory, or have been separately demonstrated to be empirically valid. Even so, in many cases, there is uncertainty about the respective parameter values. Accordingly, even in avowedly predictive models, the actual policy analytical use is limited to gaining insights into the second and higher order linkages in the economy, through runs involving different exogenous shocks, or the employment of alternative policy instruments. The quantitative predictions of such models are not taken seriously as a rule.

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[5] In fact the detailed specification by a bottom-up model may be inconsistent with the output of (typically more aggregated) top-down macroeconomic models. The inconsistency may arise from their different structures and sets of assumptions.

[6] Additionally, there are accounting models, for example I-O models, which are trivially valid.

The present study has, however, been carried out with a bottom-up, prescriptive model. If the outputs are to be useful either for macroeconomic assessments, or formulation of a strategy or national plan for abatement, they must be in the nature of credible predictions of the response of the economy to abatement commitments. There are several problems in attempting to do this. First, optimizing models are *a-priori* not credible as predictors of outcomes of essentially market economies. This is because markets do not (teleologically) seek to optimize any particular objective function, unlike the models.[7]

Second, if as a measure of *realism*, one attempts to incorporate behavioral assumptions, for example penetration rates of technologies to constrain technology choices by the model, these assumptions must be defensible on theoretical grounds, or otherwise demonstrated to be empirically valid. If they are indeed defensible, since the model outcomes are typically sensitive to the structure of assumptions, they must also be *comprehensive*. In the limiting case, the models will have unique solutions, i.e., they will no longer be optimizing models, but become predictive models. If the set of assumptions is not comprehensive, the results will not be credible as predictions, i.e., the realism in the results will be illusory because no predictive claims can be made for them.

If, on the other hand, one is uncertain about which behavioral assumptions are valid, but one wishes to explore alternative sets of assumptions, the outcome of the exercise must not be interpreted as anything more than an attempt to find out what happens when different sets of assumptions are made.

In conducting the present study, these considerations have been kept in mind. It is not possible to identify a comprehensive set of valid behavioral assumptions with respect to technology choice that may be incorporated into the model, given the present state of knowledge. Accordingly, rather than incorporating assumptions that one is uncertain about, the study has attempted to formulate a model whose structure assures that the outputs have an unambiguous interpretation. We consider that the information gained thereby to be useful, in the sense that a policymaker who formulates a strategy deviating from the least-cost path determined by the model will be enabled to identify the costs of such deviation, and rationally trade-off the possible policy advantages of such deviation against the costs. It is also useful in furnishing the set of practices which collectively "should" be pursued in the abatement strategy if energy system cost is a significant policy objective.

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[7] The economic efficiency result of a perfectly competitive market economy results from the interaction of different agents each seeking to maximize his own welfare, and not from any conscious attempt to attain economic efficiency.

1.5 Social, political and economic assessment

The final step of the GHG costing analysis is to "comment on the desirability and social, political and economic consequences of one or more alternative GHG abatement strategies". This would be difficult to do, at least in the prescribed time-frame, for two reasons. First, it is a major exercise, and requires the development and use of appropriate methodologies. Second, the study does not, because it is not supposed to, formulate abatement strategies, which may be subjected to such analysis.

What is accordingly done, is to conduct *sensitivity analyses* of the model runs in respect of three key model assumptions. These are the Plant Load Factor (PLF) of thermal power plants, foreign exchange inflows, and hydropower capacity. The first relates to the effectiveness of existing policy measures to enhance capacity utilization in the power sector, the second is a key exogenous variable whose value is extrapolated from current experience, and the third refers to possible political limitations on hydropower utilization. The results are, of course, furnished in the report, and are interesting from the policy making perspective. Unless one were expected to carry out a purely impressionistic analysis of "desirability and social, political and economic consequences", given the scope of the study we feel that this approach is valid and useful.

Table 2.1: Fuel consumption pattern by the different end-use sectors (1989/90)[8]

Units: PJ

Sectors	**Coal**	**Petroleum Product**	**Natural gas**	**Power**	**Total**
Industry[9]	1850.7	702.6	223.6	291.3	3068.2 (60.0)
Transport	94.2	1075.3	-	15.0	1184.5 (23.2)
Domestic	15.0	402.7	2.14	102.8	522.6 (10.2)
Agriculture	-	17.1	4.3	158.5	179.9 (3.5)
Others	8.6	72.8	-	64.3	145.6 (2.8)

Source: Ref [1].

2.3 Energy Supply

Total commercial energy supplies (net of changes in stocks) in India increased at an average annual growth rate of 6.9% between 1980/81 and 1989/90. Crude oil and petroleum products constitute the bulk of India's energy imports and stood at 1124.55 PJ in 1989/90.

Primary commercial energy production, imports, exports and availability for the year 1989/90 is given in Table 2.2.

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[8] Figures within the bracket are the shares of different end-use sectors in the total final energy consumption

[9] Including feedstock

Table 2.2: Production, imports and exports of primary commercial energy for the year 1989/90

Units: PJ

Energy Sources	**Production**	**Imports**	**Exports**	**Availability**
Coal	4219.7	92.5	3.4	4308.8
Oil	1460.8	1126.7	116.5	2471.0
Natural gas	621.2	-	-	621.2
Primary Electricity	241.6	-	-	241.6
Total	6541.7	1220.9	119.9	7642.7

Source: Ref [1].

As may be estimated from the above table, of the total availability, indigenous production and imports account for roughly 84% and 16% respectively of total energy consumption.

India's chief commercial energy endowments include large deposits of coal, a high potential for hydropower and nuclear power, and significant reserves of natural gas. Petroleum reserves are limited. India has extensive renewable energy sources. Considerable efforts have been made in the past decade to develop and disseminate a range of renewable energy technologies.

2.4 Structure of the Energy Sector

At present, the commercial energy development and supply industry in India lies almost entirely in the public sector, though there have recently been efforts towards privatisation. The coal industry is predominantly under the direction of the Central Government through the Department of Coal which is responsible for exploration and development, regulation of production, supply, distribution, and administered pricing of coal.

The institutional structure of the electricity subsector in India is complex. In most states, power systems are owned and operated by the State Electricity Boards (SEBs) which are responsible for the generation, transmission and distribution of power in their respective areas. Apart from these, there are a number of generating companies under the Central (Federal) Government. For example, the National Thermal Power Corporation (NTPC), the

National Hydroelectric Power Corporation (NHPC), and the Nuclear Power Corporation (NPC) together generate 30% of total electric power which is sold to the SEBs for distribution.

The chief agency involved in exploration and production of hydrocarbons is the Oil and Natural Gas Commission (ONGC) under the Ministry of Petroleum and Natural Gas (MPNG) of the Central Government. All refineries are owned and operated by the Government. In 1984, the Gas Authority of India Ltd (GAIL) was set up by the Central Government to develop the infrastructure for, and to promote the use of, natural gas.

The Ministry of Nonconventional Energy Sources (MNES) undertakes research and development projects, as well as the demonstration and extension of renewable energy systems and devices.

2.5 Energy Pricing

Commercial energy prices in India are administered by the Government, and do not in general, reflect full opportunity cost. Further, it appears that no consideration is taken of the possibility of interfuel substitution while setting these prices. For example, coal prices have been set below the costs of production and also much below the price of fuel oil (expressed in calorific terms in each case). The pricing process focuses only on the pithead costs, leaving the delivered price of coal uncontrolled. Petroleum products prices are also administered by the Government. The pricing of crude oil is complex because, in addition to producing indigenous crudes, India also imports crude oil. Therefore, crude oil prices are linked to exploration and development costs and conditions in the international crude market. Finally, consumer prices are fixed on the basis of certain political and equity considerations. Differences in consumer prices from one state of India to another are largely due to differential retail tax levies by states.

Electricity pricing is the responsibility of the State Electricity Boards (SEBs). Tariffs are often weighted by political and equity considerations, with some consumer categories paying a rate lower than the average cost of supply. Apart from this, some SEBs charge a flat rate tariff to the agricultural sector based on the connected load, irrespective of use.

CHAPTER 3

MODEL DESCRIPTION

TERI ENERGY ECONOMIC SIMULATION AND EVALUATION (TEESE) MODEL

The revised TEESE (TERI's Energy Economy Simulation and Evaluation) model provides a simple yet comprehensive representation of the energy flows in an economy. It comprises three interdependent parts (see figure below):

- The Input-output (I-O) Model
- The Reference Energy System (RES)
- The Linear Programming (LP) Framework

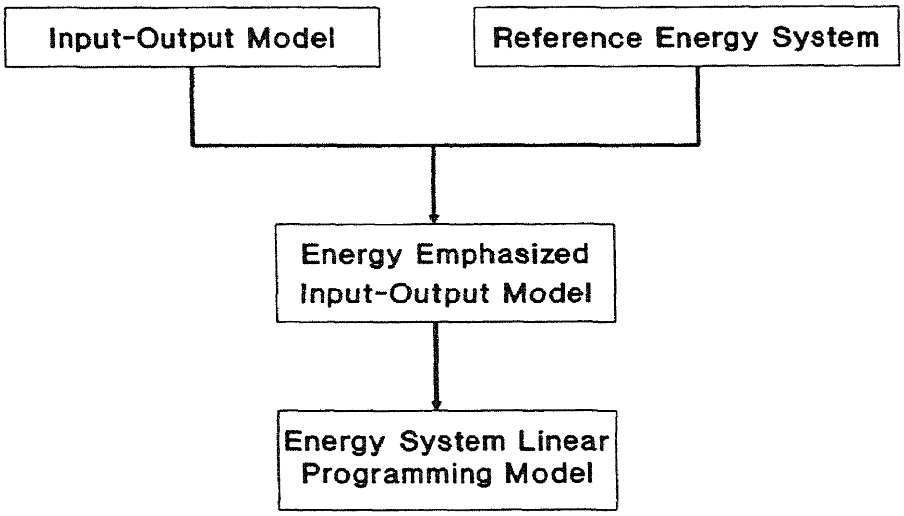
Input-Output Model
Reference Energy System
Energy Emphasized Input-Output Model
Energy System Linear Programming Model

Figure 3.1: Structure of the TEESE model

The model is **prescriptive**, rather than **predictive or behavioral**. It minimizes the total energy system cost for an exogenous vector of final demands of goods and services in the economy, choosing a subset of available technologies. Constraints in the model include limits on CO$_2$ emissions and various resource constraints. The model does not however involve any assumptions about the behaviour of individual economic agents, and cannot therefore predict actual outcomes. Detail model structure is given in Annexure 1.

CHAPTER 4
MACROECONOMIC PARAMETERS

4.1 Population

Population is an important determinant of the total energy demand in the economy. In the TEESE model, energy demand from the domestic and transport sectors is critically dependent on the total population of the country.

Over the past decade the population of India has been growing at the annual rate of 2.19%. In this study, it is assumed that this growth rate will gradually decline over time. The population figures for the terminal years of our study are shown in Table 4.1 below.

Table 4.1: Total population and distribution(%) over rural and urban areas for different terminal years.

Years	Total Population (in billions)	Percentage Urban	Percentage Rural
1989[a]	0.8274	26.9	73.1
2009[b]	1.1140	39.0	61.0
2019[c]	1.3200	47.5	52.5

Source:
a -- Ref [2]
b -- Ref [3]
c -- Own calculations, assuming that the population grows at annual average rate of 1.48% between 2009 and 2019 on the basis of expert judgement.

The aggregate rural and urban populations have been distributed by expenditure class using a log normal distribution.[10] The advantage of this approach is that it allows both the average per capita expenditure to grow and also the deviation from the mean to change over time.

It has been assumed that the ratio of the average monthly per capita expenditure for rural and urban areas to the per capita GDP remains constant over time. Data for population by expenditure class for 1988 was obtained from the extensive consumer expenditure survey carried out by the National Sample Survey Organisation [NSSO, 1990]. The poverty lines (criteria) for rural and urban areas was obtained from Minhas et. al. at 1987/88 prices [Ref 4]. These were updated to 1989/90 prices using the Consumer Price Index (general index) and are as follows:

Rural -- Rs. 136.35 per capita per month
Urban -- Rs. 176.37 per capita per month

The headcount ratios assumed for our study are shown in the table below. They are linear extrapolations of past data obtained from Minhas et.al..

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[10] A positive variable, x, is said to follow a two parameter log normal distribution (with parameters mu and α^2) if another variable defined as y = ln x follows a normal distribution. The probability density function, f(x), is defined as

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2\sigma^2}(\log x-\mu)^2\right]$$

$$\text{with mean} = e^{\mu+\frac{1}{2}\sigma^2}$$

$$\text{and variance} = e^{2\mu+\sigma^2}(e^{\sigma^2}-1)$$

The standard normal variate, z, for the poverty line provides a point of reference to calculate the probability density. For p = poverty line,

$$\frac{1}{\sigma}[\ln(p)-\mu]$$

is equal to the standard normal variate corresponding to the percentage of people below the poverty line (or the head count ratio).

Table 4.2: Percentage of people below the poverty line

Year	Rural	Urban
1989	43.32	34.66
2009	12.41	10.00
2019	8.44	6.95

Different classes based on per capita monthly expenditure as assumed in the model for the rural and urban areas are given in Table 4.3.

Table 4.3: Definition of expenditure classes (Rs per capita per month)

Class	Rural	Urban
I	0.00 - 93.02	0.00 - 95.57
II	93.02 - 149.00	95.57 - 166.87
III	149.00 - 233.04	166.87 - 285.84
IV	233.04 - 293.23	285.84 - 395.87
V	> 293.33	> 395.87

Source: Compilation from NSSO, 1990.

The final distribution of population according to expenditure class (in constant 1989/90 rupees) is shown in Fig 4.1 and Fig 4.2. As expected, over time there is an increase in the proportion of population in the higher income classes in both rural and urban areas.

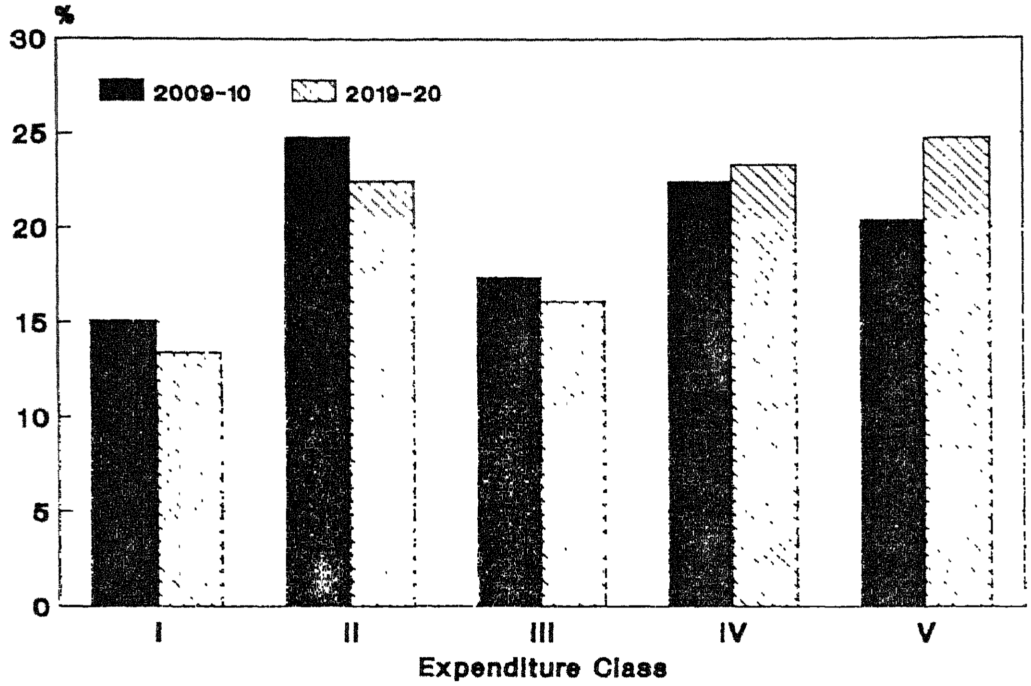

Figure 4.1: Distribution (%) of Rural Population by Expenditure Classes

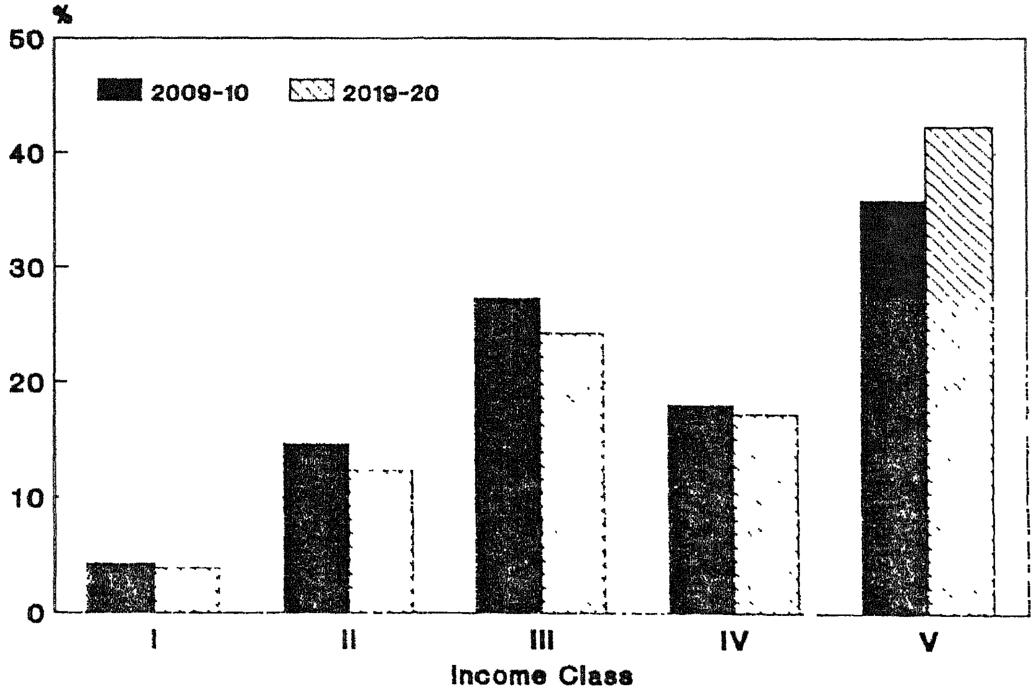

Figure 4.2: Distribution (%) of Urban Population by Expenditure Classes

4.2 Sectoral Final Demand Projection

India's GDP has grown at the annual rate of 5.8% during the Seventh Five Year Plan (1985-90). The planned rate of growth of the GDP during the Eighth Plan (1992-97) is 5.6% per annum. Sectoral growth rates of value added, as projected by the Government of India for the same period, are given below:

Table 4.4: Sectoral growth rate (value added) during 1992-97

Sectors	**Growth rate (%)**
Agriculture	3.1
Mining & Quarrying	8.0
Manufacturing	7.3
Electricity, Gas & water	7.8
Construction	4.7
Transport	6.7
Communication	6.1
Other Services	6.0
Total	5.6

Source: Ref [5].

Projected changes in the sectoral composition of GDP over the period 1991-1997 are furnished in the table below:

Table 4.5: Sectoral Composition of GDP for the years 1991/92 and 1996/97

Sectors	**1991/92**	**1996/97**
Agriculture	27.7	24.6
Industry	23.5	25.6
Services	48.8	49.8

Source: Ref [5].

For the present study, the base year is 1989 90. This choice reflects the fact that the co-efficients of the Input-Output matrix (as compiled by the Indian Planning Commission) available to us, are at 1989 90 prices.

Sectoral shares and growth rates assumed in the study for the purpose of to projecting final demand are as follows:

Table 4.6: Sectoral Composition of GDP in the different terminal years

Sectors	**1989/90**	**2009/10**	**2019/20**
Agriculture	27.0	20.2	16.4
Industry	28.0	34.8	32.3
Services	45.0	45.0	51.3

Table 4.7: Sectoral growth rate of GDP during the period (1989/90 - 2019/20)

Sectors	**Growth rate(%) 1989/90-2009/10**	**Growth Rate(%) 1989/90-2019/20**
Agriculture	4.7	4.7
Industry	7.3	7.0
Services	6.0	6.9

Note: The figures are derived from the previous table.

The growth rates of GDP for the periods 1989/90-2009/10 and 1989/90-2019/20 have been taken as 6.1% and 6.5% respectively, in the model.

CHAPTER 5

DEMAND RELATED ASSUMPTIONS FOR THE END-USE SUBSECTORS

Section 5.1: Domestic Sector

Energy demand for the domestic sector is projected for various end uses by calculating per capita energy consumption norms by expenditure class for both urban and rural areas.

Data on end use energy consumption by rural and urban expenditure class in the domestic sector is available for two years viz., 1977-78 [Ref 6] and 1987-88 [TERI, 1988]. These two data points have been used to determine the percentage distribution of energy consumption by end use for rural and urban areas separately (see Fig. 5.1). It is assumed that this percentage distribution remains constant over the period of study.

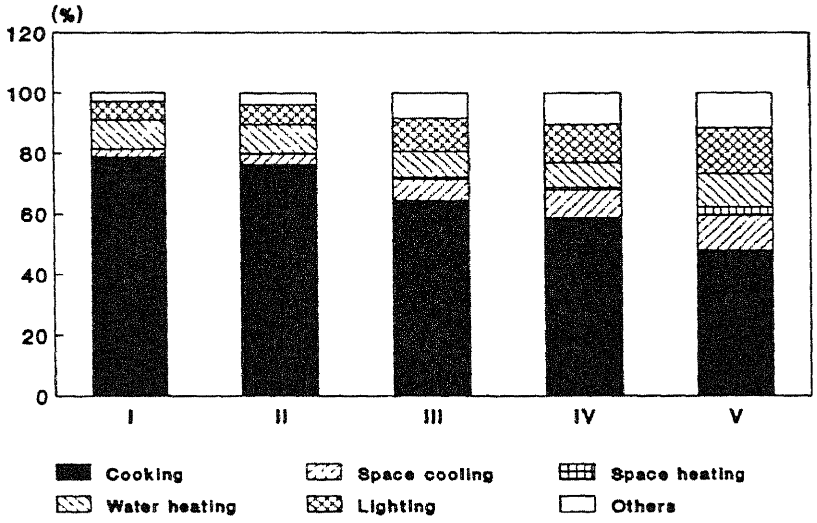

Figure 5.1: Distribution (%) of energy consumption for different end-uses in urban expenditure classes

To calculate the per capita energy consumption, a norm of 2730 KJ per capita per day and 2184 KJ per capita per day in urban and rural areas respectively, has been assumed for cooking and space heating. These norms are furnished by the Advisory Board on Energy [Ref 7]. For lighting, the standards prescribed by the Working Group on Energy Policy [Ref 8] have been used. Per capita norms for other end uses have been extrapolated from the percentage distribution of energy consumption across end uses for each expenditure class. These norms, which are assumed to remain constant, are shown in tables below.

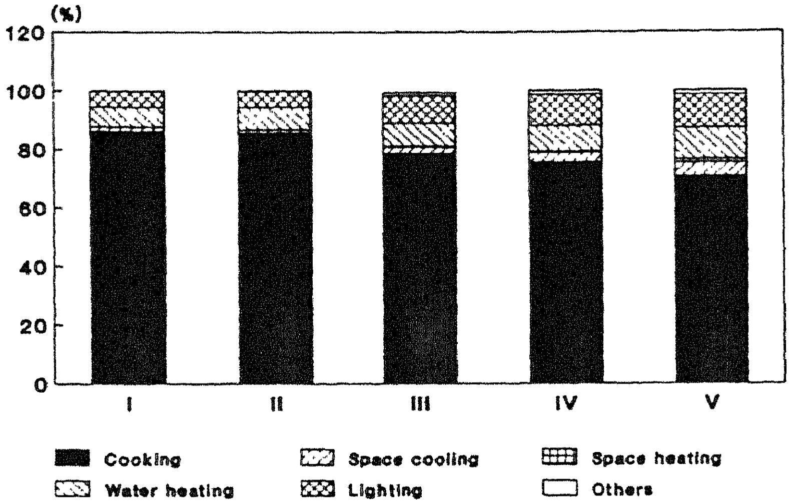

Figure 5.2: Distribution (%) of energy consumption for different end-uses in rural expenditure classes

Table 5.1: Rural energy consumption by end-use in different expenditure classes (KJ per capita per year)

End use	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**
Cooking	45320	45296	45179	45132	44654
Space heating	13	37	154	201	679
Space cooling	773	560	1551	1939	2967
Water heating	3551	4070	4468	5250	6760
Ironing	0	0	1042	1114	1267
TV	0	0	3599	3793	3921
Refrigeration	0	0	2557	2187	2141
Lighting	522	581	1345	1370	3008

Note: For lighting the figures are in lumens per capita per year.

Table 5.2: *Urban energy consumption by end use in different expenditure* classes (KJ per capita per year)

End use	Class I	Class II	Class III	Class IV	Class V
Cooking	56634	56507	56068	55772	53650
Space heating	32	159	599	895	3016
Space cooling	2000	2620	6020	8635	12179
Water heating	6824	7111	7476	7665	12199
Ironing	6699	8308	8332	10026	11519
TV	6094	14863	28794	34138	35642
Refrigeration	13073	19076	20453	19682	19464
Lighting	459	524	1293	2557	4659

Note: For lighting the figures are in lumens per capita per year.

The total energy demand by end-use for the domestic sector is the product of the per capita energy consumption and the population for each expenditure class, summed over all classes.

Section 5.2: Commercial Sector

Energy demand in the commercial sector has been found to be closely related to the gross value added by this sector. Since we do not have technology data according to end use, data on energy sales to this sector [Ref 11] have been used to estimate the energy elasticities for LPG, SKO, soft coke and electricity, with respect to value added in the sector. These are shown below.

Table 5.3: Energy elasticities with respect to value added for the commercial sector

Energy form	Elasticity
LPG	+ 1.37
SKO	+ 1.81
Soft coke	+ 1.28
Electricity	+ 1.37

Source: Regression analysis carried out by TERI.

Using these elasticities, energy demand from the commercial sector is calculated. The fuel wise projected energy demand for the terminal years of our study for the commercial sector is shown below.

Table 5.4: Energy demand from the commercial sector

Year	LPG (PJ)	SKO (PJ)	Soft coke (PJ)	Electricity (TWh)
1989	13.7	59.7	9.0	18.32
2009	21.3	271.4	2.4	85.45
2019	84.6	720.0	1.0	241.76

Source: Own calculations.

Section 5.3: Transport Sector

Passenger Transport

The per capita demand for passenger transport in India has been steadily growing over time (Figure.5.3). A time trend analysis has been carried out using past time series data on per capita passenger kilometer demand. This trend has been extrapolated into the future. Details of the regression analysis has been presented in Annexure 2. The demand for the terminal years of the study is given in the table below. The total demand for passenger transport is the product of the projected per capita demand and the projected population of the country.

Table 5.5: Per capita demand for passenger transport

Year	PKMS per capita
1989[a]	1754.39
2009	4987 27
2019	8408.74

Source: Ref [9].

In the year 1988/89, roughly 0.7% of total passenger transport demand has been met by the airways. It has been assumed in the model that 1% of total passenger transport demand will be met by airways for all the terminal years.

The percentage share of rail and road in the total passenger transport demand has also changed over time [Ref 9]. Specifically, the share of rail transport in total transport has fallen from 44.92% in 1960 to 20.98% in 1989. This trend has also been extrapolated to

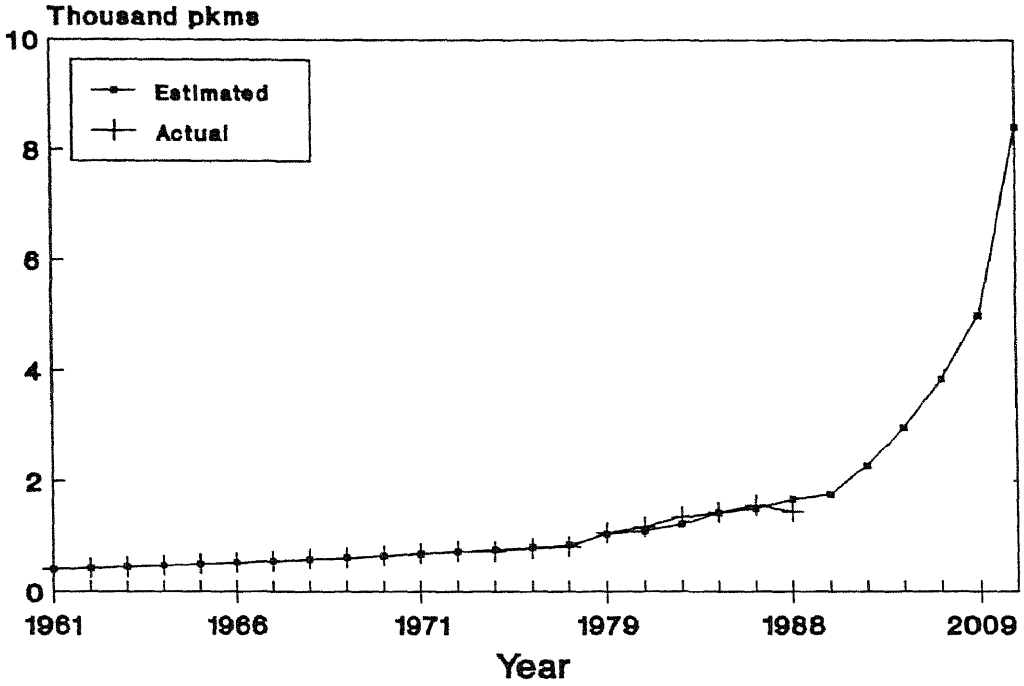

Figure 5.3: Per-capita passenger kilometer demand

determine the upper and lower bounds for the shares of rail and road in total passenger transport. For rail (road) the upper (lower) bound has been fixed at the 1989 level while the lower (upper) bound has been fixed at the extrapolated level. These are shown below.

Table 5.6: Percentage share of rail and road in total passenger transport

Year	Rail	Road
1989[a]	20.98	79.02
2009	11.54 (lower bound)	88.46 (upper bound)
2019	8.38 (lower bound)	91.62 (upper bound)

Source: Ref [9].

Freight Demand

The transport coefficients (tonne-kilometers required per unit of output) for freight for different sectors has been calculated from the input-output table furnished by the Indian Planning Commission. This table gives the value of freight services required per rupee worth of final demand for each of the sixty sectors of the Indian economy. The conversion from value to physical units has been made by assuming that the value (or price) of a tonne kilometre (TKM) remains the same as that in the base year, i.e., 1989. These coefficients are multiplied with the sectoral output of non-energy sectors and summed over all such sectors to obtain the total freight requirement. For energy commodities, this final demand is determined endogenously through the optimisation framework of TEESE.

Section 5.4: Industry Sector

Industry is an important sector of the Indian economy. The share of this sector in total GDP has grown from 12.5% in 1950 to 22.3% in 1989. This sector has also undergone structural changes which have a bearing on its energy intensity. The pattern of energy consumption in this sector is given below:

Energy consumption in industry

Industry is the single largest consumer of commercial energy in India. This sector had a share of 42% and 45 % in total power and thermal energy consumption of the country respectively in the year 1991/92. Coal, oil and natural gas are the main sources of commercial energy, of which coal has a share of 75.5% as may be observed from the table below:

Table 5.7: Fuel consumption pattern in the Industrial Sector in 1991/92.

	Consumption (PJ)	Share (%)
Coal	2087.6	75.5
Petroleum products	425.4	16.8
Natural gas	26.1	1.02

Source: Ref [1].

Other than fuel, 222.1 PJ of natural gas and 153.5 PJ of naphtha was consumed as feedstock by the fertilizer and petrochemical industries in the same year.

Eight industries account for more than 50% of the total energy consumption in this sector. These are iron & steel, cement, fertilizer, paper, aluminium, chemicals and textiles. Among them, iron and steel manufacturing is the largest energy consuming industry in the country.

Energy demand projection for the industrial sector

Thermal energy requirements for this sector has been projected for several end-uses including process heating, and iron ore reduction. Electricity requirements for three end-uses together has been estimated. These three end-uses are lighting, cooling and motor drive. Also, electricity requirement for electrolysis (to extract non-ferrous metals), and feedstock requirements for the nitrogenous fertilizer and petrochemical industries has been estimated. As far as possible, technological aspects (wet and dry process technology for cement manufacturing, Blast Furnace-Open Hearth Furnace/Basic Oxygen Furnace or Scrap/Sponge Iron - Electric Arc Furnace routes for iron and steel making etc.) have been taken into consideration. Process heating and electricity requirement (lighting, cooling and motor drive) per Rupees billion of output for each industry (except cement) have been computed using the information given in Annual Survey of Industries. Total energy requirement for process heating and electricity requirement for all industry sectors (except cement) has been determined by multiplying these two co-efficients with the outputs of the individual industries and summing them up.

Details on projections of energy requirements for cement, iron-ore reduction, and feedstock is given below:

Cement Industry

Presently, three processes are employed for cement manufacturing in the country. These are the dry, semi-dry and wet processes, which roughly account for 82%, 2% and 16% respectively of production. Wet and semi-dry processes are gradually being replaced by the dry process. The following assumptions on energy consumption and shares of different technology in cement manufacturing have been adopted in the model:

Table 5.8: The percentage shares and specific energy consumption by process in the Cement Industry

Processes	**Share(%)**	**Thermal energy (GJ/t of cement)**	**Electricity (kWh/t of cement)**
Wet	10.0	6.6	85
Dry	90.0	3.6	100

Source: Ref [3].

Iron Ore Reduction

At present, roughly 25% of steel output is contributed by scrap based electric arc furnaces. The rest is produced from iron ore reduced either in integrated steel plants or in sponge iron plants. Iron ore reduction in the country takes place in the following ways:

- using domestic or imported coking coal in Integrated Steel Plants (Blast Furnace - Basic Oxygen Furnace technology)
- making sponge iron by using non-coking coal or natural gas as reductant.

Shares and energy consumption for the different routes as adopted in the model are given below:

Table 5.9: Shares and energy consumption by fuel for Iron Ore Reduction

	Share(%)	**Energy (GJ/t of steel)**
Coking Coal	40 0	21
Imported coking coal	25.0	16.4
Non-coking coal	10.0	18.5
Natural gas	10.0	8.4

It has been assumed in the model that 15% of the steel will be produced from scrap based electric arc furnaces.

Feed stock for fertilizer

Currently, 85% of the fertilizer produced in the country is nitrogenous. It is assumed that same percentage will continue till 2019/20. Ammonia is the main intermediate input for nitrogenous fertilizer. Natural gas, fuel oil, naphtha and coal are the main fuels used as feedstock in ammonia making. Coal as a feedstock, is being phased out gradually and natural gas is becoming predominant as feedstock for ammonia manufacturing. Shares and energy consumption per tonne of ammonia for different feedstocks as adopted in the model are given below:

Table 5.10: Shares and energy consumption by different feedstocks for Fertilizer Production

	Shares (percentage) [a]	**Energy (GJ/t of ammonia) [b]**
Natural gas	67.3	31.6
Fuel Oil	17.0	39.7
Naphtha	15.7	48.3

Source: [a] Ref [3]
[b] Ref [2].

Captive power generation in the industrial sector

At present, roughly 22% of industrial power demand [Ref 11] is met by captive generation. The rest is supplied by the public utility system. Eight industries for which electricity input cost as percentage of value of output is greater than 4% are cotton textile, paper, iron & steel, cement, fertilizer, chemicals, and aluminium. In the present study, the amount of captive power generation is determined endogenously by the model. However, an upper limit has been put on captive generation. This upper limit is the total power requirement of the above eight industries, on the underlying assumption that captive power generation will remain restricted to these eight power intensive industries.

Section 5.5: Agricultural Sector

The computation of energy intensities for irrigation and land preparation is based on an analysis of historical trends and use of normative data. The greater part of the analysis deals with four major crops. This set is shared equally by food and non-food crops. The crops are paddy, wheat, cotton, and sugarcane.

Energy intensity, in this context, is the ratio of energy used by a crop to its value. Therefore, to compute the energy intensity of a crop with regard to the processes of irrigation and land preparation, we need to compute:

(a) The energy required for each crop for irrigation
(b) The energy required for each crop for land preparation
(c) The value of each crop

Energy Required for Irrigation

This calculation is performed on the following basis.

$$IR_{c,t} = AR_{c,t} * W_C * GW_t * EGW$$

where,

$IR_{c,t}$ is the energy required for irrigation for crop c in year t

$AR_{c,t}$ is the area irrigated with respect to crop c in year t

W_c is the water requirement of crop C per unit land area

GW_t is an index of groundwater potential in year t

EGW is the energy required to harvest a unit of groundwater

Energy Required for Land Preparation

Estimates of land preparation energy requirement were arrived at using a different technique. In this case, the methodology may be described as follows:

$$LP_t = GCA_t * TD_t * ARH * FC * CF$$

where,

LP_t is the energy requirement for land preparation in year t

GCA_t is the gross cropped area in year t

TD_t is the tractor density (defined blow) in year t

ARH is the average annual running hours of a tractor

FC is the fuel consumption per hour for a tractor

CF is the conversion factor to translate fuel consumption into energy use

Energy intensity of irrigation and land preparation for different crops as estimated by this method are given in Table 5.11. For details of calculations see Annexure 3.

Table 5.11: Irrigation intensity (GJ/Rs. million) for different terminal years

	1989	2009	2019
Paddy	189.8	113.4	92.3
Wheat	130.2	89.3	82.2
Other Food	82.5	45.1	31.8
Cotton	52.2	29.2	17.0
Sugarcane	178.6	109.7	89.8
Other Non-Food	46.3	22.9	14.5

Table 5.12: Energy Intensity of Land preparation (GJ/Rs. million) for different terminal years

	1989	2009	2019
Paddy	75.3	99.2	98.6
Wheat	83.3	126.9	141.2
Other Food	214.6	265.0	229.2
Cotton	67.5	66.9	43.4
Sugarcane	27.7	37.7	38.2
Other Non-Food	36.6	35.5	26.3

Section 5.6: Power Sector

At the end of 1991/92, the installed power capacity of the public utilities in the country stood at 69,082 MW with total generation of 299.2 TWh in that year. Further, 24 TWh of captive power was generated by industries in the same year for their own consumption.

The mix of generation modes of the public utility system is given below:

Table 5.13: Generation mix of the public utility system (1991/92)

Technologies	**Generation (TWh)**	**Percentage share in total generation**
Hydro	72.75	23.13
Steam	219.1	69.68
Gas turbine	13.5	4.31
Diesel & Wind*	3.5	1.12
Nuclear	5.5	1.76

Source: Ref [13].

* **Note**: The data for diesel and windpower cannot be separated.

The present level of Transmission and Distribution (T&D) losses for the Indian power system is as high as 23%. The Government of India has set a target for reduction of T&D losses of no more than 18% to be achieved in a phased manner by the year 2006/07.

Sector-wise consumption pattern of power (utilities) in the year 1991/92 is shown below:

Table 5.14: Sectoral electricity (utilities) consumption pattern in 1991/92

Sector	**Share(%) in total consumption**
Domestic	17.2
Industry	42.2
Transport	2.2
Agriculture	28.0
Others	10.3

Source: Ref [1]

Derivation of load duration curves for power supplied by public utilities

A load duration curve with four time blocks (peak, low peak, intermediate, base) a day has been generated for the power obtained from the public utility system by the following methodology:

Electricity demand from public utilities has been adjusted for transmission and distribution losses to derive the electricity delivered at the busbar. The load duration curve have been generated using the following norms as provided by the Central Electricity Authority, under the Ministry of Power, Government of India.

Table 5.15: Norms used for Load Duration Curve generation

	2009/10	2019/20
T & D losses	18.0	15.0
System Load Factor[11]	0.68	0.70
	Duration per day (hours)	All loads as fraction of peak load
Peak Load	4	1.0
Low Peak Load	2	0.8
Intermediate Load	10	0.6
Base Load	8	0.5

Once the load duration curve is generated, the load in each time block is furnished endogenously by the model.

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[11] System load factor = $\frac{\text{Average load}}{\text{Peak load}}$

CHAPTER 6
TECHNOLOGY DATA BASE

This Chapter describes the technology data base employed in the model. Supply side technologies include those from power, petroleum, coal, and renewables sectors. Demand side technologies include those in the domestic and services, agriculture, transport, and industry sectors.

The costs of the various technologies have been computed by removing the duties (excise and/or import tariffs) and sales tax from the 1989/90 market prices. The capacities of the various technologies are those that are representative for India. The technology data base incorporated in the model is limited by the lack of data. A particular problem is the fact that data on costs of operation of various technologies in the countries of origin are not disaggregated in terms of inputs costs, precluding our reworking them for Indian conditions.

The technology costing exercise has been carried for out for two different social discount rates i.e., 10% and 3%. However, simulations using the latter social discount rate have not been carried out because data on costs of production of coal, soft coke, and natural gas, and cost of washing of coal at this social discount rate are not available.

The assumptions made for calculating costs of different technologies are furnished in Annexure 5.

CHAPTER 7
ENVIRONMENT

The carbon emission factors (on the basis of carbon content) assumed for different fossil fuels are given in the table below. For petroleum products, these are furnished by the Council for Scientific and Industrial Research [Ref 14]. The emission factors for coal have been estimated on the basis of its gross calorific value and a combustion efficiency of 99%. For natural gas it is assumed that 0.51 KgC is emitted per m3 [Ref 15]

Table 7.1: Carbon emission factors

Fossil fuel	**Emission factor (tc/t of fuel)**
LPG	0.824
ATF	0.859
SKO	0.861
HSD	0.861
FO	0.880
MS	0.854
Natural gas (KgC/m^3)	0.51
Coking coal	0.685
Non-coking coal	0.531

Source: Ref [14, 15].

CHAPTER 8

CONSTRUCTION OF THE SCENARIOS

The results of any modelling exercise are critically dependant on the manner in which the reference scenario is constructed. Very briefly, reference scenarios may be constructed in one of two possible ways. In one case, it is believed that historical data and events are the best indicators of what is likely to be the "business-as-usual" scenario. In this case, the reference scenario is a linear extrapolation of past data. In the other case, however, the reference scenario is looked upon as the most desirable situation that should prevail in the absence of any efforts towards correcting the problems being studied by the model. This latter approach has been adopted by us for the purposes of this study.

The TEESE model optimises the energy system costs for the given year, subject to the constraints of the input-output model and the Reference Energy System. In this way it ensures an optimal allocation of resources within the energy sector. Since the aim of this study is to calculate the system costs of CO2 abatement options, the reference scenario does not have a CO2 constraint. In other words, the only difference between the reference scenario and an abatement scenario is that the latter has a constraint on carbon emissions. The technology set included in the model enable it to minimize costs within the carbon constraint imposed by choosing more efficient technologies as well as technologies which employ less carbon intensive fuels. Thus, the cost of abatement is the difference in the energy system cost between the reference scenario and the particular abatement scenario.

An important implication (and one that might be disconcerting at first) of constructing the reference scenario in this manner is that, by definition, there can be no negative costs of abatement, since the least cost technologies are picked up in the reference scenario.

Further, two abatement scenarios are constructed for the years 2009/10. These are 12.5% and 25% reduction in CO_2 emission from the reference scenario and are referred to as Scenario I and II respectively through out the text.

For the year 2019/20, only one abatement scenario has been considered, i.e., 23% reduction in CO_2 emissions from the reference scenario. This scenario has been referred as Scenario I for the year 2009/10. Other scenarios, i.e., 25% and 50% reduction in CO_2 emissions from the reference scenario as suggested by UNEP, do not give feasible solutions under the current set of technologies included in the model.

CHAPTER 9

ANALYSIS OF RESULTS

9.1 Demand

Energy demand by all the end-use subsectors excepting the transport sector as estimated by the model is given in Table 9.1. For the transport sector the model estimates total passenger kilometers and transport kilometers requirements which are also included in the table.

Table 9.1: Energy demand by end-use subsectors

Sectors	Units	1989/90	2009/10	2019/20
Domestic	PJ	847.6	1340.8	1780.1
Industry				
Thermal energy	PJ	1319.7	3784.5	6226.6
Electrical energy	TWh	87.0	308.0	522.0
Agriculture	PJ	220.6	386.0	591.4
Commercial				
Thermal	PJ	19.6	70.3	191.7
Electrical	TWh	17.0	85.0	241.0
Transport				
Passenger	Bill.PKMS	1451.6	5686.8	7174.2
Freight	Bill.TKMS	584.0	1812.0	3709.8

Details of end-use wise energy demand for all sectors is given in Annexure 4.

Rates of growth in energy demand over the periods (1989/90-2009/10) and (1989/90-2019/20), as estimated from the model results are given below for all sectors other than transport. In case of the transport sector, growth rates of transport demand in terms of passenger kilometers and tonne kilometers requirement are calculated.

Table 9.2: Growth rate of sectoral energy demand*

Sectors	1989/90-2009/10	2009/10-2019/20
Domestic	2.3	2.5
Agriculture	2.8	3.3
Commercial		
Thermal Energy	6.6	7.9
Electrical Energy	8.0	9.2
Industry		
Thermal Energy	5.4	5.3
Electricity	6.5	6.1
Transport		
Passenger	7.1	5.5
Freight	5.8	6.3

* For transport sector, growth rates of passenger and freight transport demand in terms of passenger kilometers and tonne kilometers are estimated.

As may be observed from the above table, the commercial sector shows the highest growth rate in energy consumption. The high growth rate in this sector (as assumed in the model which is explained in Chapter 5) is the main reason for this.

The growth rates in passenger transport demand (in PKMS) are estimated to be 7.1% and 5.5% over the periods 1989/90-2009/10 and 1989/90-2019/20 respectively, compared to the past growth rate of 8% (during the period 1970-1986). This declining trend is owing to the assumed gradual fall in the population growth rate.

In the domestic sector, energy demand for end-uses (television, refrigeration, cooling etc.) other than cooking increases at much faster rates (6.1% and 5.4% over the periods 1989/90-2009/10 and 1989/90-2019/20) than for cooking and water heating (1.8% and 3.1% respectively over the same periods). This is related to the projected upward mobility of population to higher income classes as well as migration of people to the urban areas.

In contrast to the past growth rate of 5.3% (over the period 1970-1986), electricity demand in the industrial sector is predicted to grow by 6.5% and 6.1% during the periods 1989/90-2009/10 and 1989/90-2019/20. The structural changes within the industrial sector (shift towards the engineering and equipment industry) leads to this higher growth rate in electricity demand.

9.2 Energy Supply Strategy in the Reference Scenario

Optimal fuel supply mix for the domestic sector as furnished by the model is given below:

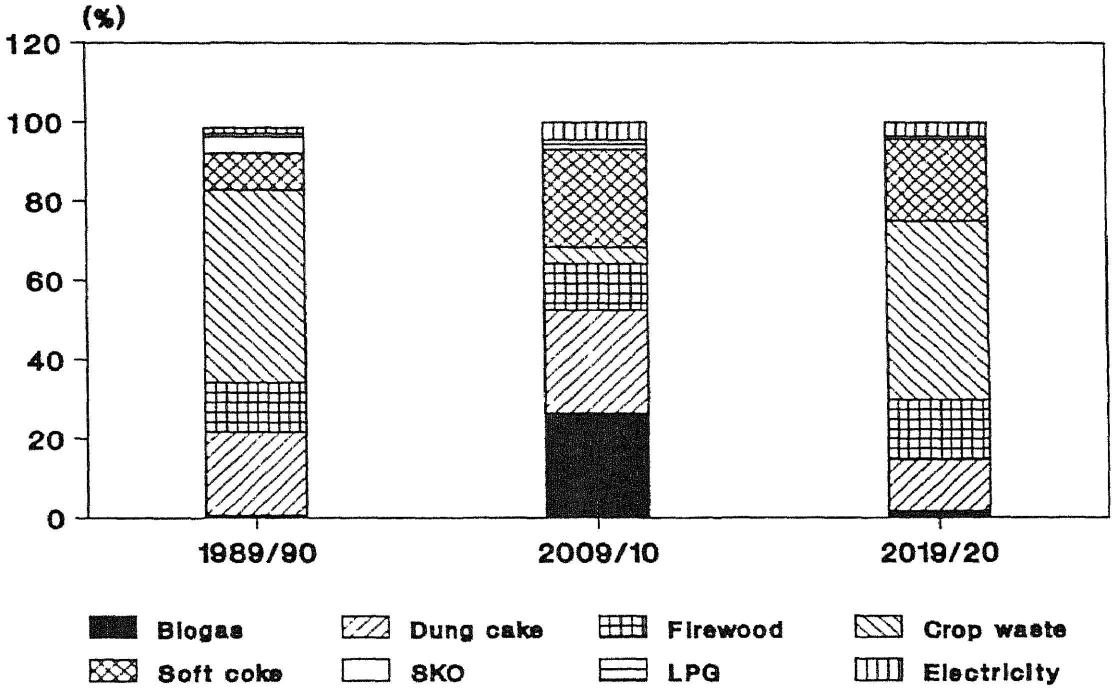

Figure 9.1: Optimal fuel-mix for the domestic sector

Details of optimal fuel and appliances mix for the domestic sector is given in the Annexure 4.

It is apparent from Figure 9.1 that as the least cost supply option, the model has opted for large quantities of traditional fuels like cropwaste, firewood, dungcake,biogas for cooking in the domestic sector, although, excepting biogas, these fuels have poor end-use efficiencies. Roughly, 85%, 73% and 79%o of energy requirement for cooking, water heating and space heating in the year 1989/90, 2009/10 and 2019/20 should be met by these fuels according to the model, because these fuels are cheap. For domestic lighting, model picks up compact fluorescent lamps (which are both economic and technically efficient) for the year 2009/10 and 2019/20. For the year 1989/90, because compact fluorescent lamps are unavailable, the model chooses fluorescent tubes for lighting which is the next most economic option.

Fans and coal based irons are chosen for space cooling and ironing respectively because they are cheaper than the alternatives, i.e., airconditioners and electric irons.

The optimal modal mix for the transport sector (passenger as well as freight) as chosen by the model is given in Figures 9.2 and 9.3.

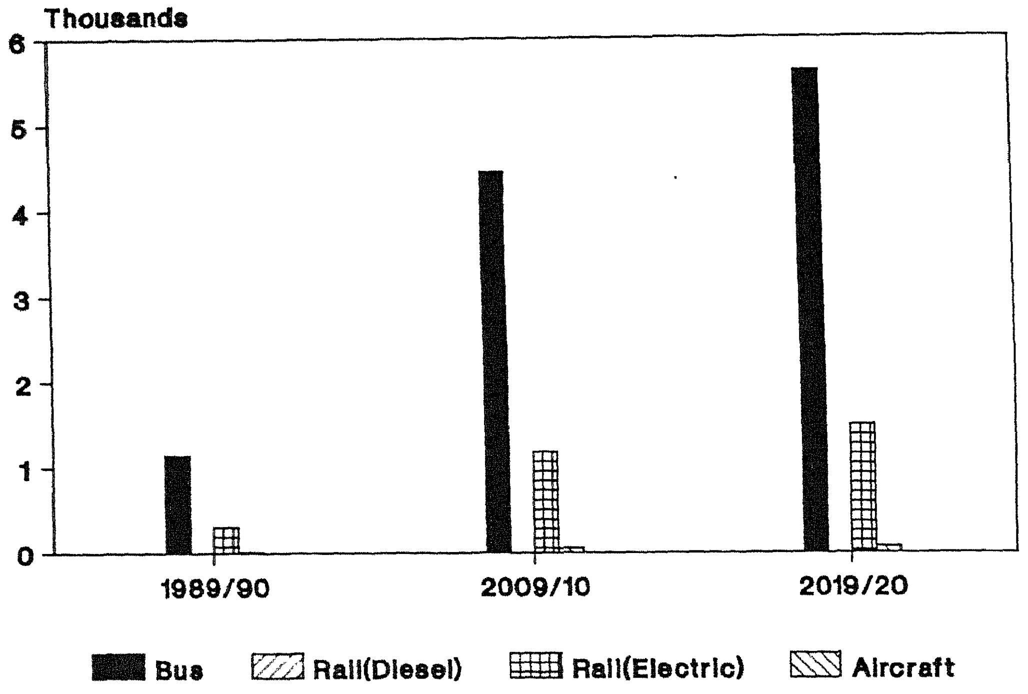

Figure 9.2: Optimal modal-mix for passenger transport

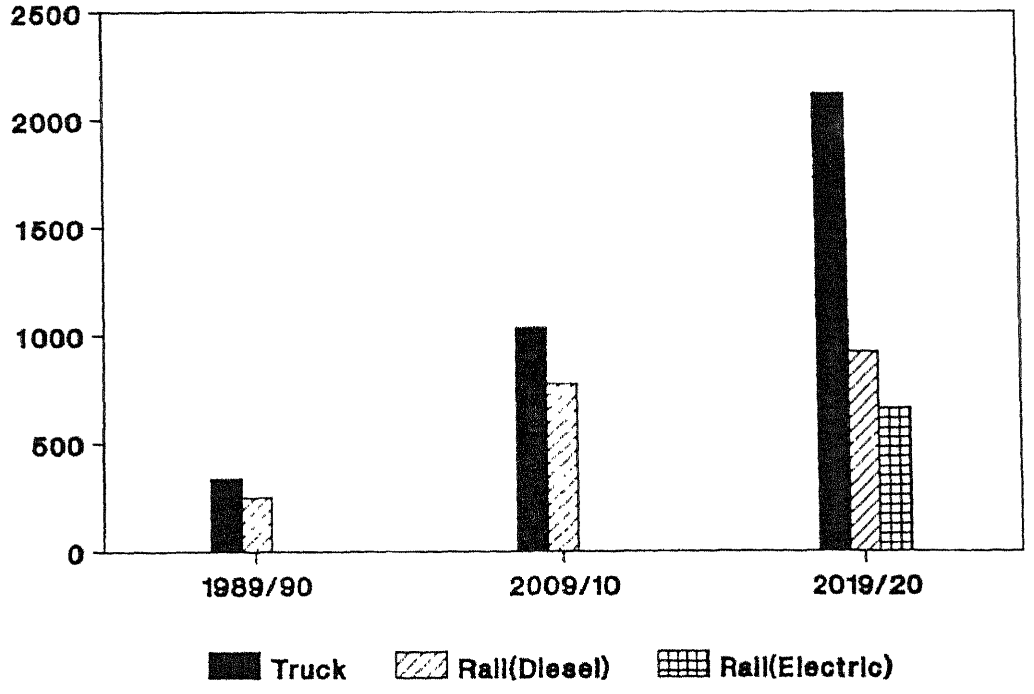

Figure 9.3: Optimal modal-mix for freight transport

The model indicates that passenger transport demand should largely be met through public bus system (78% of total demand) which is energy efficient as well as cheaper. It is assumed in the model that 1% of passenger transport demand is met by airways. The remaining demand is met by electricity driven rail transport.

For freight transport requirements, trucks (57%) and diesel driven rail transport (43%) are the best options for the year 1989/90 and 2009/10 while for the year 2019/20, approximately 18% of the demand is met by electricity driven rail transport and the remainder by trucks (57%) and diesel driven rail system (25%).

In the Industrial sector, although efficiency of coal used for process heating is low as compared to other fuels, it is the alternative chosen by the model because of low supply cost.

The model chooses diesel based pumpsets for irrigation, although device costs and efficiencies are almost same for both diesel and electricity based pumpsets. However, low conversion efficiency during electricity generation and high transmission and distribution losses makes the total system cost of diesel based pumpsets lower than that of the alternative. In the case of land preparation, the model rejects animal power altogether because of higher maintenance cost, as compared to the alternative, i.e., diesel based tractors.

The optimal electric power supply strategy as furnished by the model indicates that 42% and 40% of total industrial power requirements in 2009/10 and 2019/20 respectively should be met by captive power generation. The optimal technology-mix for power generation by utilities is given below in Table 9.3:

Table 9.3: Optimal power generation mix for the utility system

Unit: TWh

	1989/90	2009/10	2019/20
Coal (Conventional)	146	34	287
Gas (Combined Cycle)	-	210	234
Gas (Open Cycle)	2	-	8
Major Hydel	61	135	176
Nuclear	7	41	65
Coal (PCFP)*	0	0	-
Small Hydel	0	0	8
Wind	0	0	-
Solar			-
Central receiver system	0	0	-
Line focusing system	0	0	
Total	212	420	778

* Pulverised Coal Fired Plant as described in the IIASA database.

9.3 Comparison of results of the Reference Scenario vis-a-vis abatement scenarios.

2009/10

Sector-wise carbon emissions for the Reference Scenario and abatement scenarios are given below for the year 2009/10.

Table 9.4: Carbon emissions from the different sectors

Units: MT

Sectors	**Reference Scenario**	**Scenario I**	**Scenario II**
Domestic	43.0 (14.1)	9.0 (3.1)	3.1 (1.3)
Industry	150.0 (49.4)	150 (56.8)	84.0 (36.8)
Transport	48.0 (15.8)	48.6 (18.2)	57.0 (24.9)
Commercial	5.0 (1.6)	5.0 (1.9)	5.0 (2.3)
Agriculture	26.1 (8.6)	26.0(9.8)	25.0 (10.9)
Power	32.0 (10.5)	27.2 (10 2)	54.0 (23.7)
Total	303.8	265.8	227.9

Note: Figures in brackets are percentages of the respective column totals.

The table given above indicates that carbon emissions from the domestic sector have declined from 42.8 MT in the Reference Scenario to 9.0 MT in Scenario I and then further dipped to 3.1 MT in Scenario II. This has been achieved largely through complete replacement of softcoke and SKO, partly with more end-use efficient LPG and partly by fuelwood which is assumed to be GHGs neutral.

Carbon emissions from the industrial sector remains unchanged in the Reference Scenario and Scenario I but falls in Scenario II. For this scenario, the model indicates the substitution of coal by fuel oil (which has a higher end-use efficiency) for industrial process heating. No changes are observed in emissions from the transport and agriculture sectors between the Reference Scenario and Scenario I.

In Scenario II, emissions from the transport sector increases by nearly 9 MT as compared to the Reference Scenario, while they decline by 1 MT in case of agriculture. To achieve 25% reduction in carbon emissions, the model indicates a shift to diesel driven rail as opposed to electric rail in the Reference Scenario, and use of animal power for land preparation instead of diesel based tractors in the Reference Scenario, in the transport and agriculture sectors respectively. Emissions from the commercial sector remains unchanged across all scenarios. In the power sector, carbon emissions falls from 32 MT in the Reference Scenario to 27.2 MT in Scenario I. However, these rise to 54 MT in Scenario II. While the increase in carbon emissions in some sectors under abatement scenarios may seem counter-intuitive, such results may be explained by recalling that the model minimizes total system costs while adhering to a total system constraint on carbon emissions, as distinct from energy costs or emissions constraints for individual sectors.

Energy consumption, energy savings, and carbon emissions reduction in the abatement scenario over the Reference Scenario are given below:

Table 9.5: Some comparisons, Reference Scenario vis-a-vis abatement scenarios (2009/10)

	Units	Reference Scenario	Scenario I	Scenario II
Primary Energy	PJ	15791.1	13927.7	13077.9
Traditional fuels	PJ	3143.9	4117.7	4117.7
Total	PJ	18934 9	18045.4	17194.9
Total system cost	Rs bill	2906.7	2938.4	3568.3
Energy savings	PJ		889.5	1740
Carbon reduction	MT		38.0	75.9
Long-run marginal cost of carbon reduction	Rs/T		2889.0	34135.0

2019/20

For the year 2019/20, given the technology set included in the model, a maximum of 122.3 MT of carbon emissions reduction is feasible, which is 23% of the carbon emissions in the Reference Scenario. Carbon emissions by different sectors are given in Table 9.6 below:

Table 9.6: Carbon emissions from different sectors under different scenarios.

Unit: MT

Sectors	Reference Scenario	Scenario I
Domestic	69.3 (13.0)	9.9 (2.4)
Industry	221.0 (41.6)	153 (37.4)
Transport	84.0 (15.8)	96.0 (23.4)
Commercial	15.0(2.8)	15.0 (3.7)
Agriculture	40.0 (7.5)	34.0 (8.3)
Power	102.0 (19 2)	101.0 (24.7)
Total	531.5	408.9

Note: Figures in brackets are percentages of the respective column total.

It is apparent from the above table that there is a substantial reduction in emissions from the domestic sector in the abatement scenario over the Reference Scenario. Soft coke consumption has been substituted by LPG, SKO and firewood which results in 86% decline in carbon emissions over the Reference Scenario. A substantial reduction in carbon emissions can be observed in the industrial sector.

To achieve this reduction, the model suggests the following options: 1) Substitution of coal by fuel oil for process heating and 2) captive power generation by using pulverised coal fired power generation technology.

Due to the same reason, carbon emissions from the agriculture and transport sector in the Scenario I follows the similar trends as in Scenario II for the year 2009/10.

Energy consumption, savings and reduction in carbon emission in the abatement scenario over the Reference Scenario are given below:

Table 9.7: Some comparisons, Reference Scenario vis-a-vis abatement scenario (2019/20)

	Units	Reference Scenario	Scenario I
Primary Energy	PJ	26034.6	22200.1
Traditional fuels	PJ	6542.0	6990.5
Total	PJ	32576.6	29190.6
Total system cost	Rs bill	4476.3	5647.1
Energy savings	PJ		3386.0
Carbon reductions	MT		122.3
Long-run marginal cost of carbon reductions	Rs/T		35096.0

9.4 Sensitivity Analysis

Sensitivity analysis runs have been carried out for each of the above scenarios in respect of two important policy variables, i.e., foreign exchange inflows and hydropower capacity. Additionally, sensitivity analysis for each scenario has also been carried out for a critical data parameter, the plant load factor (PLF) for thermal power plants. The results are compared in each case with those of the corresponding Standard Abatement Scenario (SAS) runs, and are furnished below.

I Year: 2009/10, 12.5% CO_2 reduction:

In separate runs, foreign exchange inflow was reduced by 37.5% from SAS, hydropower capacity was fixed at 19,192 MW (1991-92 level) as opposed to an upper bound of 50,000 MW in SAS, and assumed PLF was reduced from 63% to 58% (i.e., a fall of 5%).

In the case of **reduced foreign exchange inflow**, the tightening of this constraint leads to increased energy system cost (+31.6%) but a *fall* in aggregate CO_2 emitted (-11.1%), i.e., the CO_2 constraint in this case becomes *slack*. The fall in foreign exchange inflow results in a sharp change in imports, exports, and domestic production of petroleum based fuels. Imports of crude increases significantly (by 971%), while that of ATF falls by 45%, and that of HSD disappears altogether. On the other hand, while domestic production of crude is unchanged, that of petroleum products ATF, LPG, SKO, FO, HSD, MS and Naphtha increase appreciably (by 133% in each case). The increased output also enables increased exports of products: LPG, SKO, MS, and Naphtha, helping to meet the more stringent foreign exchange constraint. There is also a shift in the structure of energy related CO_2 emissions: the percentage shares of natural gas and LPG show increase, while that of non-coking coal significantly declines; this would explain why the CO2 constraint is slack in this case.

In the case of **freezing hydropower capacity at 1991-92 levels**, the energy system cost increases (6%), but the CO_2 constraint remains tight (i.e., CO_2 cutback from Reference Scenario remains at 12.5%). As one would expect, in this case the share of hydropower in total electricity generation falls sharply (from 30.6% to 13.8%), while that of coal based generation increases (from 14.4% to 57.8%). The share of nuclear based generation increases slightly (8.9% to 10.1%) but that of gas based power falls appreciably (from 46% to 18.3%). There is no change in use of different forms of biomass and solar energy, and the chief adjustments are in respect of fossil fuel production and trade. Coking coal production decreases (48%) but that of petroleum products increase significantly (14%), supported by increased imports of crude (744%) and increased exports of the more GHGs intensive fractions (SKO, MS, naphtha) and non-coking coal, the more GHGs benign fraction (LPG) virtually completely replacing SKO in the domestic sector.

The sensitivity analysis simulation of the parameter **Plant Load Factor for thermal power plants** reveals only a slight increase in energy system cost (0.8%), the CO_2 constraint remaining tight. In this case, there is a sharp fall in the share of coal in total power generation (from 14.4% to 4.2%) and increase in share of gas based (46.0% to 52.9%), of nuclear based, (8.9% to 9.4%), and of hydropower (30.6% to 33.5%). There is correspondingly, a fall in share of CO_2 emissions attributable to non-coking coal (45.5% to 42.4%) and increase in the shares of fuel oil (2.4% to 4.0%) and HSD (24.4% to 25.9%). The increase in shares of emissions from FO and HSD may be explained by their substitution for thermal electricity in several applications, because the price of electricity increases due to lower PLF.

II Year: 2009/10, 25.0% CO_2 reduction:

Separate sensitivity analyses were conducted for reduction of foreign exchange inflow by 37.5% from the SAS, fixation of hydropower capacity at 1991-92 levels, and reduction in PLF for thermal power plants by 5% from 63% to 58%, as in the previous scenario.

In the case of **reduced foreign exchange inflow**, once again (i.e., as in the previous scenario) there is substantial increase in energy system cost (+48.9%), but this time the CO_2 constraint remains tight. The major adjustment is a large increase in crude oil imports (+143%) and exports of value added products, i.e., HSD and MS. Further, there is massively increased production of coking coal (+332%), almost all of the increase being exported. The principal adjustment of fuel use in the national economy is increased use of non-coking coal, whose share of CO_2 emissions rises from 12.8% to 31.1%, principally offset by reduced use of fuel oil whose share of emissions falls from 25% to 13.4%. Since Fuel oil use is based on crude oil imports, this result is plausible.

The **freezing of hydropower capacity** (at 1991-92 levels) also results in significant increase in energy system cost (+45.3%), while the CO_2 constraint remains tight. The principal adjustment, in line with the severe tightening of this constraint is fall in the share of hydro in total power generation (from 27.1% to 6.6%). This is accompanied by significant increase in the share of coal based power generation (26.9% to 38.7%) and of gas based generation (38.4% to 45.9%). There is also a modest increase in nuclear based generation (7.6% to 8.8%). Adherence to the CO_2 constraint is ensured by increased use of non-coking coal and reduced use of HSD. The CO_2 emissions from these two fuels accordingly increase from 12.8% to 16.3%, and fall from 31.7% to 28.5%, respectively. The changes in emissions from other fuels is relatively minor.

In the case of **decrease in assumed PLF for thermal power plants** there is a slight increase in energy system costs (+2.6%) and the CO_2 constraint remains tight. The other changes in shares of electricity generation by coal, gas, nuclear and hydropower replicate the results of the previous scenario.

III Year 2019/20: 23% Reduction of CO_2 from Reference Scenario:

Sensitivity analyses in this scenario involve, first, the reduction of exogenous inflow of foreign exchange from 4.6% of GDP in Reference Scenario to 3.7% (i.e., a fall of nearly 20%), second, freezing of hydropower capacity at 1991-92 levels (i.e., 19,192 MW) as opposed to an upper bound of 60,000 MW in Reference Scenario, and finally, reduction in assumed PLF for thermal generating plants from 63% to 58%, i.e., a drop of 5%.

In the run involving **reduction in foreign exchange inflow**, there is a sharp increase in energy system cost (+39%), the CO_2 constraint remaining tight. The major adjustment to the tighter foreign exchange constraint, as in the case of the two previous scenarios, are in the patterns of production, imports, and exports of fossil fuels. The economy attempts to earn the shortfall in foreign exchange by massive increase in imports of crude (+70.8%), and exports of value added products: SKO, HSD, MS, Naphtha, ATF and LPG, the imports of ATF and FO in the SAS disappearing in the process. Fuel use patterns in the national economy, reflected in the relative CO_2 emissions from each, show increase in non-coking coal emissions (from 25.4% to 30.0%), balanced by fall in share of emissions from SKO (4.5% to 3.4%), fuel oil (22.5% to 21.5%) and HSD (28.2% to 24.8%).

No feasible solution exists in the case when **hydropower capacity is constrained to 1991-92 levels**. In other words, the economy is unable to effect a 23% reduction in CO_2 emissions from the Reference Scenario situation in 2019/20 if hydropower capacity is restricted to present levels.

In the case of **PLF for thermal power plants being assumed at 58% instead of 63%**, there is slight increase in energy system cost (+3.3%), and the CO_2 constraint remains tight. As in the previous two scenarios, lowering the assumed level of PLF for thermal power plants reduces the share of coal based plants in total power generation (from 42.4% to 36.9%), while the shares of gas based (28.4% to 31.4%), nuclear based (7.9% to 8.2%) and hydropower based (21.3% to 23.5%) power generation all increase. Again, in line with the results of change in this parameter for the previous scenarios, there is slight increase in use of non-coking coal and SKO in the economy, balanced [to maintain the aggregate constraint on CO_2 emissions], by slight fall in use of LPG and HSD.

Overall, the result of the sensitivity analyses conform well to intuitive expectations, and are consistent across the different scenarios. While the adjustment to fall in exogenous inflow of foreign exchange in each scenario, mainly the increased import of crude oil and export of value added petroleum products [and coal] enabling BOP to be maintained, may not be plausible in the real world, this result does point to the importance of the external sector in enabling the national economy to adhere to possible reduction commitments. The importance of hydropower capacity development in formulating abatement strategies is also clearly brought out by the sensitivity analyses. Further, costs of abatement increase sharply whenever these two policy constraints are tightened, (and a feasible solution exists), attesting to their significance.

CHAPTER 10

CONCLUSION

The India country study has contributed to useful knowledge in the field of national GHG abatement costing studies in at least the following ways: First, a fairly large database of technologies in both production and energy sectors has been built up, including actual costs in India. This database is in a format which permits expansion easily. Second, the TEESE model has been updated, revised, and recast in a more easily understood and better documented software. The further development of this model and incorporation of a larger data set is now relatively simple. Third, useful experience has been gained in carrying out an abatement costing study in terms of a set of uniform guidelines. While this experience has revealed several problems in the outlined objectives and specification of methodology, it has also furnished results which are useful from a policymaking perspective, and which have an unambiguous interpretation.

In particular, the study has focussed attention on the correct interpretation and use of the results of simulations of formal quantitative models for policy analysis. The evolving discipline of policy analysis has emerged in response to the need of policymakers for *scientific answers* to policy problems. However, due to the inherent nature of the subject matter of study, i.e., real world policy problems, it is not feasible for policy analysts to follow the accepted scientific method of the physical sciences in all respects, and in particular, in the matter of empirical validation. This limitation casts a particular responsibility on policy analysts to adhere stringently to the other canons of the scientific method. These include being explicit about uncertainty, peer review, and open debate about alternative approaches and explanations. The team of researchers for the present India country study would be gratified if their experience in conducting the study contributes to the evolution of a methodological framework for abatement cost studies which passes these tests.

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Annexure 1

Model Description

A1.1 The I-O Model

The standard Leontief I-O model can be represented by the following set of equations:

$$A\,x + y = x \tag{1}$$

where A is the input-output coefficients matrix; x is the vector of gross outputs, and y is the final demand vector. Each element of the A matrix, a_{ij}, gives the quantity of commodity i required to produce one unit of the gross output of commodity j. In the TEESE model this structure has been retained for all non-energy commodities. For energy commodities, the model prescribes an energy use pattern to enable the minimization of total energy system costs, subject to the constraints formed by the I-O equations and the RES.

In order to capture the energy flows in the economy, all production sectors have been classified into 3 categories, i.e., energy supply, energy products and non-energy products. The "energy product" sectors capture the different end uses of energy such as cooking, lighting, electric drive, and so on. They are not marketed production sectors, but are involved in production and consumption activities. The "energy supply" sectors are real energy products including primary energy forms (e.g., coal, crude oil, natural gas etc.), and secondary energy forms (e.g., electricity). The "non-energy" sectors are all the other sectors that consume the energy end uses, e.g., households, industries etc. The flow of energy from the energy supply sectors to the non-energy sectors is routed through energy products. That is, energy sources are converted into different end uses through various devices. For instance, kerosene consumed by the domestic sector is converted to the end use through which it is consumed say, cooking, and flows into the domestic sector through this energy product.

Accordingly, the vectors x and y in equation (1) are partitioned to reflect the three way categorisation of sectors. This means that,

X = X_s -- vector of gross outputs of the energy supply sectors
X_p -- vector of gross outputs of the energy products
X_i -- vector of gross outputs of the non energy products,

and (2)

Y = Y_s -- final demand vector for energy supply sectors
Y_p -- final demand vector for energy product sectors
Y_i -- final demand vector for non-energy product sectors.

where subscript s indicates energy supply; subscript p indicates energy products, and subscript i indicates non-energy products.

Equation (1) can then be written as follows:

$$A_{ss}x_s + A_{sp}x_p + y_s = x_s \tag{3}$$

$$A_{ps}x_s + A_{pi}x + y_p = x_p \tag{4}$$

$$A_{is}x_s + A_{ii}x_i + y_i = x \tag{5}$$

This implies that the A matrix has been further subdivided into 9 submatrices, as shown below.

$$A = \begin{array}{lll|l} \text{Energy supply} & \text{Energy product} & \text{Non-energy} & \\ \hline A_{ss} & A_{sp} & A_{si} = O & \text{Energy} \\ (\text{Kcal/Kcal}) & (\text{Kcal/Kcal}) & (\text{Kcal/RS}) & \text{supply} \\ \hline A_{ps} & A_{pp} = O & A_{pi} & \text{Energy} \\ (\text{Kcal/Kcal}) & (\text{Kcal/Kcal}) & (\text{Kcal/Rs}) & \text{product} \\ \hline A_{is} & A_{is} = O & A_{ii} & \text{Non-energy} \\ (\text{Rs/Kcal}) & (\text{Rs/Kcal}) & (\text{Rs/Rs}) & \\ \hline \end{array} \tag{6}$$

where,

A_{ss}: Input-output coefficents describing the flows of energy from one energy sector to another (including conversion losses). Since the production of energy supplies consumes energy, A_{ss} is (typically) positive. It should be noted that while the primary energy forms are consumed as feedstock, their energy content largely remains unimpaired.

A_{sp}: These coefficients capture the conversion of energy supplies to energy end uses. They represent the end use conversion efficiencies or device efficiencies;

A_{si}: By definition, these coefficients are zero since non-energy sectors cannot directly consume the output of the energy supply sectors. This is done indirectly through one or more of the energy products. For example, steel making needs coal, and electricity only through the end-uses "process heat" and "electric drive";

A_{ps}: These are input-output coefficients describing how energy products or final energy forms are used by the energy supplying sectors. For example, electricity used for lighting a refinery would be included here;

A_{pp}: These are zero by definitions, since one end-use cannot "consume" another;

A_{pi}: These coefficients describe the relationship between the energy products and the final energy consuming sectors. For example, they may describe the amount of electric drive needed to produce a unit of steel output.

A_{is}: The energy supplying sectors also require some non-energy materials during the production process. For example, coal has to be transported from the pit-head to the power station. This is captured by the A_{is} coefficients.

A_{ip}: Non-energy products are not used for the production of energy products. Therefore, by definition, these coefficients are zero.

A_{ii}: These are the standard I-O coefficients describing the amounts of non-energy commodities needed per unit of gross output of non-energy product.

It should be noticed that in matrix (2), all energy factors are measured in energy units (calories or giga joules), while all non-energy products are measured in monetary terms (rupees in our case).

The I-O system is driven by the vector of final demands, [Y]. For a given vector of final demands, the gross output may be calculated by means of equation (1), given the fixed coefficients technology sets represented by the A matrix. The vector of final demands is exogenous to the model.

A1.2 The Reference Energy System (RES):

The RES is a linear network which captures the energy flows from the energy supply sectors to the final energy consuming sectors, via energy end uses. At one end are the energy resources: nuclear, hydropower, coal, wood, crop and animal waste, crude oil, natural gas, solar, wind, etc. The other end includes the energy consumption sectors: residential, commercial, industries, agriculture, and transportation. In between, there are some intermediate stages: extraction, energy refining and conversion, energy transportation and storage, central station conversion, transmission, distribution and storage, decentralized conversion, utilizing device, and demand categories (end uses). To illustrate, we have shown below a section of the RES that captures the flow of coal.

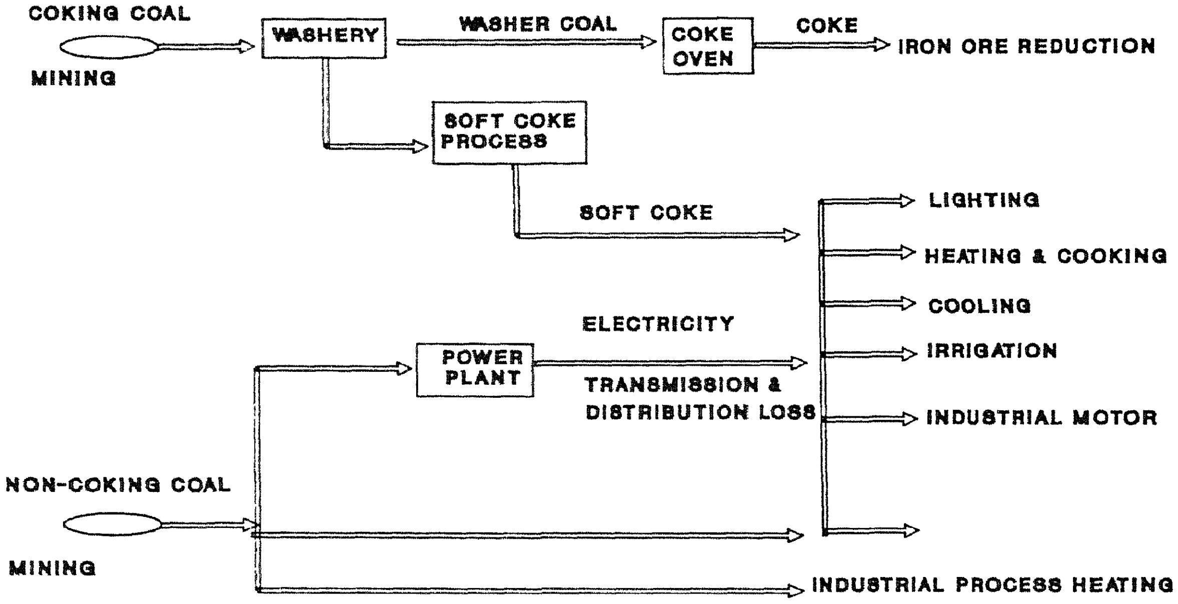

Figure A1.1: Reference energy system for coal

Note that not all energy resources must pass each intermediate stage. For example, wood would directly enter the decentralized conversion i.e., energy product stage after transportation and storage.

The interaction between the I-O model and the RES, forms the energy emphasised I-O model (EIO) equations (4)-(6). All energy extractions form x_s, the total outputs of energy resource supplies in the EIO model. All imports and exports of energy sources are y_s, the final demand for energy sources as well as those in the ordinary I-O model. On the end use side, the residential and commercial demand categories would serve as y_p, the final demand for energy end-uses in the EIO model. The industrial, agricultural and transportation demand categories would serve as x_p in the EIO model.

The intermediate stages which provide energy end uses by real energy supply forms are "decentralized conversion" and "utilizing devices". Accordingly, A_{sp} in the EIO model appear in these two stages. A_{ss} in the EIO model appears in all stages before these two stages and after extraction, mainly in stages "central station conversion" and "transmission distribution and storage".

The Reference Energy System (RES) model serves a basic framework of energy flows and the energy system linear programming model.

A1.3 The Linear Programming Framework

At the core of the TEESE model is the linear programme which minimises energy system costs subject to the equations of the I-O model, the RES, and other equations that determine the demand for energy.

The objective function is as follows:

$$
\begin{aligned}
S=&\sum_{i} c_{\xi} x_{i}+\sum_{j} c_{yj} y_{j}+\sum_{k} c_{sk} s_{k} \sum_{l} c_{Il} I_{l}+\sum_{n} c_{En} E_{n} \\
&+CRF(r,m)\,[\sum_{i} \Pi_{\xi} x_{i}+\sum_{j} \Pi_{yj} y_{j}+\sum_{k} \Pi_{sk} s_{k}+\sum_{n} \Pi_{EN} E_{n}]
\end{aligned}
\qquad (7)
$$

where

S - energy system cost

C_{xi} - the non-fuel operating and maintenance cost of converting energy from x_i;

x_i - intermediate energy (i.e., the output of energy conversion and refining)

C_{yi} - the non-fuel operating and maintenance cost of the end-use device y_i;

y_i - end-use device utilization;

c_{sk} - non-fuel operating and maintenance cost of energy source s_k;

s_k - domestic supplies of energy, where k = coal, gas, crude oil, fire-wood, crop waste, dung etc.;

c_{Il} - CIF cost of imported fuel I_l;

I_l - imports of energy sources;

c_{En} - non-fuel operating and maintenance cost for electric plant;

E_n - electric plants of type n, where n = hydro, gas, coal, lignite, nuclear and diesel.

CRF (r,m) the capital recovery factor (for interest rate r and amortization period m);

Π_{ijt} - capital cost for the corresponding capital stock variable J_i.

In the above equation, $\sum c_i x_i$ furnishes costs of energy conversion (excluding electricity); $\sum c_{yj} y_j$ gives costs of energy consumption; $\sum c_{sk} s_k$ stands for costs of primary energy production; $\sum c_{Il}$ furnishes cost of energy import; $\sum c_{En} E_n$ gives cost of electricity production. Electricity production has been considered separately.

Constraints

n this section, we explain the constraints of the LP in detail.

Supply constraints

All primary energy sources have been given upper bounds which represent the limit of availability of energy resources in terms of sustainable yield, or optimal extraction rates, or physical potential, as appropriate.

Population Related Energy Demand and Supply

. Domestic sector energy demand [illegible]

Energy demand in the domestic sector is directly related to population. The population of the country has been classified into 5 expenditure classes for both rural and urban areas. Per capita norms for each end-use K are determined exogenously of the model. The total energy demand for each end-use is therefore:

$$\sum_{i=1}^{5} P_{ki}^{r} R_i + \sum_{i=1}^{5} P_{ki}^{u} U_i = TD_k \qquad (8)$$

where,

- the income class

R_i - population of rural income class i;

U_i - population of urban income class i;

P^u_{ki} - per capita energy demand for end use k by the i-th income class of the urban population;

p^r_{ki} - per capita energy demand for end-use k by the i-th income class of the rural population;

TD_k - total energy demand for end-use k; and

end-use k: cooking, water heating, lighting, cooling, heating, and others.

The energy demand for a particular end-use may be met using different devices which in turn may use different fuels. For example, lighting energy demand may be met through kerosene, biogas or electricity (using incandescent bulbs, fluorescent tubes or compact fluorescent bulbs). The demand constraints for the domestic sector are:

$$\sum_t \eta_{kt} F_{kt} = TD_k \qquad (9)$$

where,

Π_{kt} - the efficiency of device q using fuel t for end-use k;

F_{ktq} - the utilization of fuel type t in device q to meet the energy end-use k.

2. Transport sector: Passenger transport

The demand for passenger transport is also directly linked to population. The total demand for passenger transportation is the product of the per capita demand and total population. In other words:

$$\sum_{i=1}^{5} (R_i + I_i) * PCPKM = ED_{pkm} \qquad (10)$$

where,

R_t and U_t are as explained in equation (8)

PCPKM - per capita demand for passenger transport

ED_{pkm} - total demand for passenger transport on PKMS.

This demand may be met through various modes of passenger transport (cars, buses, etc.) using different fuels. The demand supply constraint for passenger transport is therefore:

$$\sum_{t,q} \alpha_{tq} F_{tq} = ED_{pkm} \tag{11}$$

where,

α_{tq} - efficiency of ρ^{th} device using the t^{k} fuel for meeting demand for passenger transport.

F_{tq} - total use of the ρ^{th} device using the t^{th} fuel for the passenger transport end use.

Production Related Energy Demand and Supply

The energy demand by the production sectors is given as:

$$\sum_{i} P_{ki} C_i = ED_k \tag{12}$$

where,

P_{ki} - the k-th energy end-use required for production of one unit of the i-th good;

C_i - the total production of the i-th good;

ED_k - the total energy demand for the k-th energy end-use.

The supply constraints are given by:

$$\sum_{t,q} \beta_{ktq} F_{ktq} \geq ED_k \qquad (13)$$

$$\sum_{t} \beta_{kt} F_{kt} - \sum_{i} P_{ki} C_i \geq 0 \qquad (14)$$

where,

β_{ktq} - the efficiency of the ρ^{th} device using the t^{th} fuel for end-use k;

F_{ktq} - the total use (in heat units) of the ρ^{th} device using the t-th fuel for end-use k;

ED_k - total energy demand for end-use k.

The production sectors are broadly separated into three categories: agriculture, industry and commercial sectors, and I indicates a particular production sector in a given category. Accordingly, the above equation covers all end-uses in each production category.

For agriculture, the energy end-uses considered are irrigation and land preparation. (15)

For industry, the energy end-uses are electric drive, ore reduction, lighting, cooling, feedstock, process heating, and electrolysis. (16)

Electricity Sector Constraints

Electrical energy should be supplied in such a way that it will meet the demand at different time blocks. Four modes of generation are considered: peak, low peak, intermediate and base. The relevant equations are as follows:

$$AVGLD=\frac{TOELD*(1+\alpha)}{8760} \qquad (15\ a)$$

$$L_p=\frac{AVGLD}{SLF} \qquad (15\ b)$$

$$L_i=\beta_i*L_p \qquad (15\ c)$$

for i ≠ base,

$$\sum_m (1-\gamma_m)*G_{im}=(L_i-L_{(i+1)})*t_i \qquad (15\ d)$$

for i = base,

$$\sum_m (1-\gamma_m)*G_{im}=L_i*t_i \qquad (15\ e)$$

$$\sum G_{im}\leq\delta_m*K_m*8760 \qquad (15\ f)$$

where,

TOELD - total electricity demand in the economy

AVGLD - average load of the national power system

SLF - system load factor defined in Chapter 4

L_i - load at i-th time block

α - transmission and Distribution losses

i - 1,2,3,4 for peak load, low peak load, intermediate load and base load respectively

β_i - i-th load as a fraction of peak load given in Chapter 4

t_i - duration of i-th load

G_{im} - electrical energy generation (in gwh) from the m-th type of power plant during i-th demand block

m - plant type (hydro, nuclear, conventional coal thermal, gas based open cycle etc.)

ρ_m - auxiliary consumption in the plant type m

δ_m - plant load factor of the m-th type plant

Non-Energy Sector Constraints

The non-energy sector constraints from the I-O model are the following:

$$A_{ij}x_j + y_i = x_i \qquad (16)$$

Balance Equations

This set of constraints ensures that the model maintains individual energy balances in the system:

$$F_k = S_k + I_k - X_k \qquad (17)$$

where,

F_k - total demand for fuel k;

S_k - domestic production of fuel k;

I_k - imports of fuel k;

X_k - exports of fuel k.

Balance of payments constraint

Since TEESE is an open economy model, a constraint on the balance of payments is necessary to close the system.

The input-output part of the model provides the import and export coefficients for non-energy commodities in monetary terms. The product of these and the corresponding gross output provides the total value of trade on current account due to non-energy commodities. For the energy commodities, the linear programme furnishes the quantities of exports and imports. These are multiplied with the respective border prices, and the total value of trade due to energy commodities is obtained. In this way the quantities of imports and exports of energy commodities are decision variables.

India has received considerable foreign remittances (and aid) over the past decades. We assume that the situation will not be very different in the foreseeable future and that net foreign funds inflow as a proportion of GDP will remain fixed. This forms the upper bound on the balance of payments.

$$(E_i.X_i - M_i.X) + BP_s.X_s \leq v.GDP$$

where,

E_i is the export coefficient for non-energy commodity i,

M_i is the import coefficient for non-energy commodity i,

X_i is the gross output of the non-energy commodity i,

BP_s is the border price for energy supply commodity s,

X_s is the gross output of the energy supply commodity s,

v is an exogenously determined constant.

Annexure 2

Time trend analysis of per-capita passenger kilometer demand

A2.1 Semi-log relationship: $P = ae^{bt}$,

P - per-capita passenger kilometer demand
t - time
a,b - constants

Constant = -41.88
Standard error of P estimate = 0.02
R^2 = 0.99
No. of observations = 22
Degrees of freedom = 20
X co-efficient = 0.0227
Standard error of X coefficient = 0.0005
t-statistic = 43.399

A2.2 Double-log relationship: $P = at^b$

Constant = 2.407
Standard error of P estimate = 0.083
R^2 = 0.824
No. of observations = 22
Degrees of freedom = 20
X co-efficient = 0.454
Standard error of X coefficient = 0.04699
t-statistic = 9.6808

Annexure 3

Calculations of the Energy Demand for the Agricultural Sector

A3.1. Irrigation

Area Irrigated: Irrigated areas under the crops considered were computed on the basis of projections made from data spanning thirty six years i.e. from 1953 to 1988.[1] The results of the regressions performed are given below.

Paddy Projections (m ha)

1989	18.41
2009	22.69
2019	24.83

Regression Output

Constant	- 406.98
Std Err of Y Est	0.28
R Squared	0.99
No. of Observations	36.00
Degrees of Freedom	34.00
X Coefficient(s)	0.21
Std Err of Coef.	0.00
t statistic	48.32

Cotton Projections (m ha)

1989	2.77
2009	3.65
2019	4.08

Regression Output

Constant	- 96.83
Std Err of Y Est	0.09

Source: Agriculture Statistics at a Glance (1991), Ministry of Agriculture.

R Squared	0.97
No. of Observations	36.00
Degrees of Freedom	34.00
X Coefficient(s)	0.05
Std Err of Coef.	0.00
t statistic	33.08

Wheat Projections (m ha)

1989	19.09
2009	28.65
2019	33.42

Regression Output

Constant	- 931.34
Std Err of Y Est	1.23
R Squared	0.95
No. of Observations	36.00
Degrees of Freedom	34.00
X Coefficient(s)	0.48
Std Err of Coef.	0.02
t statistic	24.27

Sugarcane Projections (m ha)

1989	2.47
2009	3.46
2019	3.96

Regression Output

Constant	- 84.59
Std Err of Y Est	0.05
R Squared	0.99
No. of Observations	36.00

Degrees of Freedom	34.00
X Coefficient(s)	0.04
Std Err of Coef.	0.00
t statistic	56.74

Water Requirement: The water requirement of a crop is determined on the basis of scientific experiments. The following norm for different crops is described in Rao (1979).[2]

Water Requirement (m^3 per ha)

Paddy	36,000
Wheat	12,000
Cotton	15,000
Sugarcane	50,000

Groundwater Index: The index of groundwater potential for the country is an indicator of the contribution that this source can make relative to the other important source of irrigation i.e. surface water. For the base year, the index GW is defined as the

$$GW_{BASE} = \frac{Current\ Groundwater\ Potential}{Current\ Irrigation\ Potential}$$

where,

Current Irrigation Potential is the sum of Current Groundwater Potential and Current Surface Water Potential. Analogously, the index for the terminal years is defined on the basis of the 'ultimate' potentials since the country is expected to be close to or achieve these in the next 15-20 years. The numerical values of these indices turn out to be 40% and 34% respectively.[3]

Energy Requirement: The energy required to lift a cubic metre of water through a head height h is 13.7*h KJ. Given that the head height varies from 10 to 40 metres in the country, we assume an average head height of 20 metres. Therefore, every cubic metre of water lifted requires 273.4 KJ of energy.

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[2] Rao, K L (1979), India's Water Wealth, Orient Longman Ltd., New Delhi.

[3] *Source*: Seventh Five Year Plan (1985-90).

For other crops, since extensive data was not available, the energy requirement was computed as follows. The fraction of irrigated area under paddy and wheat is 85% of area irrigated under food crops and that under cotton and sugarcane is 40% of area under non-food crops. Therefore, the energy requirement of other food crops is estimated to be 17.65% ([100-85]/85) of paddy and wheat taken together. Analogously, the of non-food crops is estimated to be 150% ([100-40]/40) of cotton and sugarcane taken together.

A3.2 Land Preparation

Gross Cropped Area: The gross cropped area was projected on a basis similar to the one adopted for projecting irrigated area. The regression results are as follows.[4]

Paddy (m ha)

1989	42.17
2009	48.54
2019	51.54

Regression Output

Constant	- 554.56
Std Err of Y Est	0.97
R Squared	0.93
No. of Observations	41.00
Degrees of Freedom	39.00
X Coefficient(s)	0.30
Std Err of Coef.	0.01
t statistic	23.43

Cotton (m ha)

1989	7.69
2009	8.06
2019	8.21

---

[4] *Source*: Agriculture Statistics at a Glance (1991), Ministry of Agriculture.

Regression Output

Constant	- 20.40
Std Err of Y Est	0.69
R Squared	0.06
No. of Observations	42.00
Degrees of Freedom	40.00
X Coefficient(s)	0.01
Std Err of Coef.	0.01
t statistic	1.62

Wheat (m ha)

1989	23.50
2009	33.11
2019	37.14]

Regression Output

Constant	- 776.03
Std Err of Y Est	1.19
R Squared	0.95
No. of Observations	42.00
Degrees of Freedom	40.00
X Coefficient(s)	0.40
Std Err of Coef.	0.02
t statistic	26.57

Sugarcane (m ha)

1989	3.44
2009	4.25
2019	4.68

Regression Output

Constant	- 82.40

Std Err of Y Est	0.22
R Squared	0.86
No. of Observations	42.00
Degrees of Freedom	40.00
X Coefficient(s)	0.04
Std Err of Coef.	0.00
t statistic	15.61

Tractor Density: The tractor density projections are based on time-series data.[5] Using this, a regression exercise yielded the following results.

Tractor Density Projections
(# per m ha)

1989	5852
2009	12108
2019	15236

Regression Output

Constant	-616285.59
Std Err of Y Est	292.05
R Squared	0.97
No. of Observations	17.00
Degrees of Freedom	15.00
X Coefficient(s)	312.79
Std Err of Coef.	14.46
t statistic	21.63

---

[5] *Source*: Basic Statistics Relating to the Indian Economy (Vol. I), CMIE, August 1992.

Annual Running Hours: A range of estimates by various bodies are available in this regard.[6] These lie in a narrow range: from 900 to 1200. For our analysis, we make the assumption that the number of annual running hours of a tractor is 1000, which is the same as the GOI-ESCAP study.

Fuel Consumption: This number was also based on the GOI-ESCAP assumption of 0.325 litres per hr.

Bringing together these assumptions and computations, we get the following results.

Energy Required for Irrigation (PJ)

	1989	2009	2019
Paddy	57.9	62.5	68.4
Wheat	20.0	26.3	30.7
Other Food	13.8	15.7	17.5
Cotton	3.2	4.0	4.5
Sugarcane	12.1	13.9	15.6
Other Non-Food	23.0	26.9	30.3

Energy Required for Land Preparation (PJ)

	1989	2009	2019
Paddy	22.7	54.7	73.1
Wheat	12.8	37.3	52.7
Other Food	35.8	92.0	125.8
Cotton	4.2	9.1	11.6
Sugarcane	1.9	4.8	6.6
Other Non-Food	18.2	41.7	54.9

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[6] For example, studies have been conducted by the Planning Commission, the Government of India (GOI) & ESCAP and the Tata Energy Research Institute.

Estimated Value of Output (Rs. million)			
	1989	2009	2019
Paddy	305273	551357	740978
Wheat	153795	294407	373301
Other Food	166837	347351	548949
Cotton	62086	136038	268332
Sugarcane	67818	127086	173970
Other Non-Food	497252	1173419	2085687

Energy Intensities: Finally, projections of energy intensities were obtained by computing the ratio of energy requirements of various crops to their estimated values. The final results are as follows.

Irrigation Intensity (GJ per Rs. million)			
	1989	2009	2019
Paddy	189.8	113.3	92.3
Wheat	130.2	89.3	82.2
Other Food	82.5	45.1	31.8
Cotton	52.2	29.2	17.0
Sugarcane	178.6	109.7	89.8
Other Non-Food	46.3	22.9	3.45

Land Preparation Intensity (GJ per Rs. million)

	1989	2009	2019
Paddy	75.3	99.2	98.7
Wheat	83.3	126.9	141.2
Other Food	214.6	265.0	229.2
Cotton	67.5	66.9	43.4
Sugarcane	27.7	37.7	38.2
Other Non-Food	36.6	35.5	26.3

Annexure 4
Results
Reference Scenario

Table A401: Optimal demand of commercial and traditional fuels in the reference scenario

	Units	1989/90	2009/10	2019/20
Commercial Energy				
Natural gas	PJ	409 92	2228.1	2620.8
Coal	PJ	4331.0	7469.8	13652.5
Petroleum product	PJ	2693.3	5047.6	8862.0
Electricity	TWh	213.0	490 0	891.0
Traditional Fuels				
Crop waste	PJ	2224.1	188.8	4136.6
Firewood	PJ	573.7	537.5	1013.7
Dung cake	PJ	969.3	1196.2	1196.2
Biogas	PJ	27.3	1219.9	193.6
Solar	PJ	0 5	0.99	1.93

Table A402: Final sectoral energy demand by end-uses.

Units: PJ

	Units	**1989/90**	**2009/10**	**2019/20**
Domestic Sector				
Cooking	PJ	697.3	978.7	1253.7
Lighting	Billion Lumens	5.29	11.3	16.0
Water heating	PJ	83.2	143.5	195.7
Space heating	PJ	6.7	18.9	29.0
Space cooling	PJ	43.7	100.8	150.0
Television	PJ	17.6	45.9	71.4
Ironing	PJ	5.9	14.7	22.7
Refrigeration	PJ	11.3	27.0	41.6
Total	PJ	847.6	1340.8	1780.1
Agricultural Sector:				
Irrigation	PJ	126.5	147	223.9
Land preparation	PJ	94.1	239.0	367.5
Total	PJ	220.6	386.0	591.9
Industrial Sector: *Thermal energy requirement*				
Process heating	PJ	700.0	2267.6	3676.1
Feedstock	PJ	359.4	462.2	1222 6
Ore reduction	PJ	259.7	1064.7	1327 9
Total	PJ	1319.7	3784.5	6226.6
Industrial Sector: *Electricity requirement*				

Electricity for cooling, lighting, motor drive	TWh	67.0	259.0	456.0
Electricity for electrolysis	TWh	20.0	49.0	66.0
Total	TWh	87.0	308.0	522.0
Transport Sector:				
Passenger	Billion PKMS	1451 6	5686.8	7174.2
Freight	Billion TKMS	584.0	1812.0	3709.8
Commercial Sector:				
Electricity	TWh	17.0	85.0	241.00
Heating energy	PJ	19.6	70.3	191.7

Table A403: Optimal primary commercial energy production and import in the reference scenario

Unit: PJ

	1989/90	**2009/10**	**2019/20**
Domestic Production			
Crude	1428	2960.6	3360
Natural gas	1560.3	2228.1	2620.8
Coal	4244.5	12614.7	16153.2
Electricity	245.6	635.7	890.94
Import			
Coal	36.5	78.6	103.3
Petroleum	965	2776.9	4001
Crude	836.7	-	3066.0

Table A404: Optimal energy supply mix for the domestic cooking in the years 1989/90, 2009/10, 2019/20

Unit: PJ

	1989/90	**2009/10**	**2019/20**
Biogas	27.3	1100.8	11.4
Dung cake	969.3	1196 2	1196.2
Firewood	573.7	537.5	504
Crop waste	2224.1	-	3942.0
Soft coke	380.3	767.8	1709.0
SKO	193.9	60.1	-
LPG	42.8	-	-
Electricity	55.1	-	-
Total	4466.5	3662.4	7362.6

Table A405: Optimum fuel mix (by type of appliance) for different end-uses excluding cooking

Units: PJ

End-uses	**1989/90**	**2009/10**	**2019/20**
Space Heating			
Dung cake	-	-	-
Crop waste	-	188.8	193.6
Electricity	7.79	-	-
Kerosene	-	-	-
Total	7.79	188.8	193.6
Lighting			
Bulb	-	-	-
Fluorescent tube	0.8	-	-
Compact fluorescent lamp	-	1.15	1.6
Petromax	-	-	-
Kerosene lamp	-	-	-
Total	0.8	1.15	1.6
Television	11.95	54.05	84
Water Heating			
Biogas	-	119.2	132.2
Crop waste	-	-	-
Dung cake	-	-	-
Firewood	-	-	862.2
Soft coke	-	255.4	-
Solar	0 5	0.99	1.93
LPG	-	52 7	76.1

SKO			
Immersion rod	103.8	-	-
Geyser			
Total	104.3	428.3	1072.4
Cooling			
Cooling fan	57.2	118.5	176.4
Airconditioner	-	-	-
Total	57.2	118.5	176.4
Refrigerator	12.56	30.0	46.1
Ironing			
Coal	48.2	122.5	190.5
Electricity	-	-	-
Total	48.2	122.5	190.5

Table A406: Optimal energy supply mix in the Industrial sector for various end-uses.

	Units	1989/90	2009/10	2019/20
Process heating				
Natural gas	PJ	-	-	-
Coal	PJ	1082.8	3299.5	4723.3
Oil	PJ	210.0	157.5	463.3
Total	PJ	1292.8	3457	5186.6
Feed stock				
Natural gas	PJ	139.2	32.0	479.8
Fuel oil	PJ	139.0	314.7	571.8
Naphtha	PJ	81.2	115.5	171.0
Total	PJ	359.4	462.2	1222.6
Ore reduction				
Domestic coking coal	PJ	208.5	798.4	987.0
Domestic non-coking coal	PJ	14.7	87.8	104.8
Imported coal	PJ	36.5	78.6	103.3
Natural gas	PJ	-	100.5	132.0
Total	PJ	259.7	1064.7	1327.9
Lighting, cooling, and motor drive				
Electricity	TWh	67.0	259.0	456.0
Electrolysis				
Electricity	TWh	20.0	49.0	66.0

Table A407: Optimal fuel mix for the transport sector

Fuels	Units	1989/90	2009/10	2019/20
Electricity	TWh	5	40	43
HSD	PJ	677.9	2037.9	5806.4
MS	PJ	-	-	-
ATF	PJ	146.4	573.4	722.9

Table A408: Optimal device and energy mix for the Agricultural Sector

Unit: PJ

	1989/90	2009/10	2019/20
Irrigation			
Pumpsets (diesel)	690.9	420.8	640.7
Pumpsets (electricity)	-	-	-
Land preparation			
Tractor	377.6	955.7	1470.5
Animal power	-	-	-

Table A409: Optimal power generation mix for the public utility system

Unit: TWh

Technologies	**1989/90**	**2009/10**	**2019/20**
Coal (conventional)	146	34	287
Gas (combined cycle)	-	210	234
Gas (open cycle)	2	-	8
Hydel	61	135	176
Nuclear	7	41	65
Coal (PCFP)*	-	-	-
Small hydel	-	-	8
Wind	-	-	-
Solar	-	-	-
Central receiver system	-	-	-
Line focusing system	-	-	-
Total	212	420	778

* Pulverised coal fired plant

Table A410: Optimal captive power generation mix

Unit: TWh

Technologies	**1989/90**	**2009/10**	**2019/20**
Gas (combined cycle)	25	-	-
Coal (conventional)	20	143	229
Coal (PCFP)	-	-	-

Table A411: Carbon emissions from various fuels*

Unit: MT

	1989/90	2009/10	2019/20
Natural gas	3.7 (2.2)	28.1 (9%)	31.6 (5.9)
Coal	109.4 (65.7)	188.6 (62.1)	344.8 (65%)
Petroleum products	47.1 (28.2)	87.0 (29%)	154.9 (29)
Total emissions	166.6	303.8	531.5

* Figures in brackets are percentage shares of different fuels in total emission

Table A412: Carbon emissions from the different sectors*

Units: MT

Sectors	1989/90	2009/10	2019/20
Domestic	24.2 (14.5)	43.0 (14.1)	69.3 (13.0)
Industry	54.9 (33.0)	150.0 (49.4)	221.0 (41.6)
Transport	15.2 (9.1)	48.0 (15.8)	84.0 (15.8)
Commercial	1.7 (0.1)	5.0 (1.6)	15.0 (2.8)
Agriculture	20 2 (12.1)	26.1 (8.6)	40.0 (7.5)
Power	50.4 (30.2)	32.0 (10.5)	102.0 (19.2)
Total	166.6	303.8	531.5

* Figures in brackets are percentage shares of different fuels in total emission

Abatement Scenarios

Table A413: Optimal Demand of commercial energy and traditional fuels in the abatement scenarios

	Units	2009/10		2019/20
		Scenario I	**Scenario II**	**Scenario I**
Commercial fuel				
Natural gas	PJ	2228.1	2228.1	2620.1
Coal	PJ	5828.6	2057.6	5203
Petroleum product	PJ	5217.6	8102.2	13441.5
Electricity	TWh	490 0	461.0	868.0
Traditional fuel				
Crop waste	PJ	188.8	188.6	4136.8
Fire wood	PJ	1512	1512	1512
Dung cake	PJ	1196.2	1196.2	1196.2
Biogas	PJ	1219.7	1219.9	143.6
Solar	PJ	0.99	0.99	1.9

Table A414: Optimal Production and import strategies of primary commercial fuel

Units: PJ

	2009/10		**2019/20**
	Scenario I	**Scenario II**	**Scenario I**
Domestic production			
Natural gas	2228.1	2228.1	2620.1
Coal	10921.5	9883.9	3360
Crude	2960.6	2960.6	3360.0
Electricity	653.8	668.1	934.9
Import			
Crude	535.5	7369.7	13146.0
Coal	78.6	78.6	103.3
Petroleum products	2557.4	1210.4	1790.9

Table A415: Optimal energy supply mix for domestic cooking under abatement scenarios for the years 2009/10 and 2019/20

Units: PJ

	2009/10		**2019/20**
Fuels	**Scenario I**	**Scenario II**	**Scenario I**
Biogas	1100.8	1100.8	11.4
Dung cake	1196.2	1196.2	1196.2
Firewood	1512	1512.0	1512.0
Crop waste	-	-	3942.0
Soft coke	-	-	-
SKO	-	-	-
LPG	36 9	36.9	317.5
Electricity	-	-	-
Total	3845.9	3845.9	6979.1

Table A416: Optimal end-use device and energy mix for the domestic sector for all end-uses excluding cooking

Units: PJ

	2009/10		**2019/20**
	Scenario I	**Scenario II**	**Scenario I**
Space heating			
Dung cake	-	-	-
Crop waste	188 8	188.8	193.6
Electricity	-	-	-
Kerosene	-	-	-
Total	188.8	188.8	193.6
Lighting			
Bulb	-	-	-
Fluorescent tube	-	-	-
Compact fluorescent lamp	1 15	1.15	1.6
Petromax	-	-	-
Kerosene	-	-	-
Total	1 15	1.15	1.6
Television	54.05	54.05	84
Water Heating			
Biogas	119 2	119.2	132.2
Crop waste	-	-	-
Dung cake	-	-	-
Firewood	-	-	-
Soft coke	-	-	-
Solar	0.99	0.99	1.93
LPG	29.2	129.3	10.4
SKO	120.1	-	231.8
Immersion rod	103.8	-	-
Geyser	-	-	-

Total	373.5	249.5	376.3
Cooling			
Fan	118.5	-	-
Air conditioner	-	112.1	166.8
Total	118.5	112.1	166.8
Refrigerator	30.0	30.0	46.1
Ironing			
Coal	122.7	122.7	15.1
Electricity	-	-	26.9
Total	122.7	122.7	42.0

Table A417: Optimal energy supply mix in the Industrial sector for various end-uses

Units: PJ

		2009/10		**2019/20**
	Units	**Scenario I**	**Scenario II**	**Scenario I**
Process heating				
Natural gas	PJ	-	-	-
Coal	PJ	3149.2	-	-
Oil	PJ	279.3	2838.2	4596.3
Total	PJ	3428.5	2838.2	4596.3
Feed stock				
Natural gas	PJ	324	324	479.8
Fuel oil	PJ	314.6	102.9	152.6
Naphtha	PJ	115 5	327.3	530 3
Total	PJ	754 1	754.2	1162.6
Ore reduction				
Domestic coking coal	PJ	798.4	798.4	987.8
Domestic non-coking coal	PJ	87.8	87.8	104.8
Imported coal	PJ	78.6	78.6	103.3
Natural gas	PJ	100 5	100.5	132.0
Total	PJ	1064 7	1064.7	1327.9
Lighting, cooling & motor drive				
Electricity	TWh	259.0	259.0	456.0
Electrolysis				
Electricity	TWh	49 0	49.0	66.0

Table A418: Optimal modal and energy mix for the transport sector under the abatement scenarios

	Units	**2009/10**		**2019/20**
		Scenario I	Scenario II	Scenario I
Passenger transport				
Bus	Billion PKMS	4448.8	4448.8	5612.4
Rail (diesel)	Billion PKMS		1181.2	1490.1
Rail (electricity)	Billion PKMS	1181.2	-	-
Air	Billion PKMS	56.9	56.9	71.7
Total	Billion PKMS	5686.9	5686.9	7174.2
Freight transport				
Truck	Billion TKMS	1035.2	1060.0	2153 5
Rail (diesel)	Billion TKMS	-	794.0	1614.0
Rail (electricity)	Billion TKMS	775.9	-	-
Total	Billion TKMS	1811.1	1854.0	3767.6
Energy supply				
Electricity	TWh	40	-	-
HSD	PJ	2039.3	2480.7	4286.5
MS	PJ	-	-	-
ATF	PJ	573.4	573.4	722.9

Table A419: Optimal device and energy mix for the agricultural sector under the abatement scenarios

Units: PJ

	1989/90	**2009/10**	**2019/20**
Irrigation			
Pumpsets (diesel)	420 8	420.8	640.7
Pumpsets (electricity)	-	-	-
Land preparation			
Tractor	955 7	902.2	1153.3
Animal power	-	13.4	79.3

Table A420: Optimal power generation mix for the public utility system under the abatement scenarios

Unit: TWh

	2009/10		**2019/20**
Technologies	**Scenario I**	**Scenario II**	**Scenario I**
Coal (conventional)	-	-	-
Gas (combined cycle)	209	207	233
Gas (open cycle)	-	-	-
Hydro	140	146	176
Nuclear	41	41	65
Coal (PCFP)*	66	144	348
Small hydel	-	4	8
Wind	-	-	10
Solar			
Central receiver system	-	-	-
Line focusing system	-	-	-
Total	456	542	840

* Pulverised coal fired power plant

Table A421: Optimal captive generation mix in the abatement scenarios

Unit: TWh

	2009/10		**2019/20**
Captive power generation	**Scenario I**	**Scenario II**	**Scenario I**
Coal (conventional)	111	-	-
Gas (combined cycle)	-	-	-
Coal (PCFC)	-	4	135

Table A422: Carbon emissions from various fuels for the different abatement scenarios*

Unit: MT

Fuels	**2009/10**		**2019/20**
	Scenario I	**Scenario II**	**Scenario I**
Natural gas	28.1 (10.6)	28.1 (12.0)	31.6 (7.7)
Coal	147.3 (55.4)	51.9 (23.00	131.5 (32.1)
Petroleum products	90.5 (34.0)	147.8 (65.0)	246.1 (60.0)
Total	265.8	227.8	409.3

* Figures in brackets are percentage shares

Table A423: Carbon emissions from the different sectors*

Unit: MT

Sectors	**2009/10**		**2019/20**
	Scenario I	**Scenario II**	**Scenario I**
Domestic	8.0 (3.1)	3.1 (1.3)	9.9 (2.4)
Industry	151 (56.8)	84.0 (36.8)	153 (37.4)
Transport	48.6 (18.2)	57.0 (24.9)	96.0 (23.4)
Commercial	5.0 (1.9)	5.0 (2.3)	15.0 (3.7)
Agriculture	26.0 (9.8)	25.0 (10.9)	34.0 (8.3)
Power	27.2 (10.2)	54.0 (23.7)	101.0 (24.7)
Total	265.8	228.1	408.9

* Figures in brackets are percentage shares

Annexure 5

Assumptions

Assumptions for annual energy consumption of lighting devices

Chirag - 1/28 litre*4hrs*365days
Lantern - 2/28 litre*4hrs*365days
Petromax - 1/2 litre*4hrs*365days
FL1 20W - 32 watts*7hrs*365days
FL2 20W - 52 watts*7hrs*365days
FL2 40W - 45 watts*2555hrs
HP sodium vapour lamp - 275 watts*12hrs*365days
Sodium vapour lamp (using PV) - 500 watts*12hrs*365days

Assumptions for annual energy consumption of domestic appliances

Kerosene wick stove - 1litre*365days
Kerosene pressure stove - 0.75litre*365days
LPG stove - 14.2kg*12months
Biogas stove - 1m3*360days
Coal Iron - 2kg*365days
Electric hotplate - 1.5KW*10% (6hr*365days)
Microwave oven - 60watts*10%(6hr*365days)
Mixer - 400 watts*.5hr*365days
Geyser p.a. - 1.5 Kw*2hrs*365dyas
Room heater - 1.5 Kw*3hr*122days
Immersion rod - 1.5 Kw*2hrs*365days
Refrigerator - 120watts*14hrs*365days
TV - 60watts* {(5hrs*5days*4weeks*12months) + (10hr*2days*4weeks*12 months)}
Electric oven - 500watts*10%*2190hrs
Electric iron - 750watts*.5hr*365days
Fan - 60watt*16hrs*365days
AC(1 ton) - 1800 watts* (1920hrs-2016hrs)
AC(1.5 ton) - 2400 watts*(1920hrs_2016hrs)
HP sodium vapour lamp - 275watts*12hrs*365days
Room cooler - 250watts*16hrs

Solar cooker - 700watt/m2*3hrs*0.25 (area)*40%*300days
Solar water heating system - 0.03114kwatt/litre*50litres*365days

Assumptions for the agriculture sector

Diesel consumption per tractor (tonnes/year) - 2.5
Utilisation rate of electric pump (Kwh/year) - 4423
Consumption of a diesel pump (litres/year) - 883

Assumptions for the transport sector

Roadways

	Capacity	Load factor	Av. dist. p.a (kms)
Passenger			
2W Scooter	2	1.6	9000
2W Motorbike	2	1.6	9000
Car	4	2.6	9500
Jeep	6	2.6	9500
Freight			
Delivery van	0.7	0.4	1000
Pick up van	0.7	0.4	1000
Truck	8	0.66	58000
Bus	52	0.86	70000
3-W passenger	3	1.76p/v	25000

Airways

Av. distance covered per trip	823 kms
No. of trips in a day	4
Capacity	191
Load factor	70%
pkms per annum	131865067

Railways

Passenger

Diesel	844 (av. no. of passengers per train) * 109146000 kms (train ki
Electric	67259204000

Freight

Diesel	831.9 (net tonne km.)*80(av. no. of wagons)*300 days
Electric	38848320

Assumptions for the power sector

Plant load factor of a coal fired plant - 63%
Plant load factor of a gas (combined cycle) plant - 63%
Plant load factor of a gas (open cycle) plant - 63%
Plant load factor of a nuclear plant - 63%
Plant load factor of a hydro plant - 35%
Plant load factor of a pumped storage plant - 35%
Plant load factor during transmissions - 65%
Plant load factor of a captive plant - 70%]
Capacity utilisation factor of a wind farm - 20%
Capacity utilisation factor of a wind farm - 12%
Capacity utilisation factor of a wind farm - 30%